NOAA Technical Memorandum NOS OMA 25

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A FIELD TRIAL OF THE SEDIMENT QUALITY TRIAD IN SAN FRANCISCO BAY

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EXECUTIVE SUMMARY

The objective of this study was to assess the utility of the Sediment Quality Triad approach in augmenting the field measurements of the National Status and Trends Program. The Triad consisted of coincident measurements of sediment contamination by chemical analyses, sediment toxicity through performance of laboratory sediment bioassays, and infaunal community structure by collection of benthic macroinfauna data. The Triad approach is based upon the observation that each component complements and adds to the information provided by the other two components in assessments of pollution-induced degradation. The hypothesis underlying this concept is that no individual component of the Triad can be used to predict the results of the measurement of the other components. This hypothesis was tested in this study with synoptic measurements of the Triad components at three separate sites in San Francisco Bay: Islais Waterway, near Oakland, and in San Pablo Bay. At each site, ten stations were sampled. Sediment samples collected from three of the ten stations at each site were categorized using four separate, replicated sediment bioassays, comprehensive sediment chemistry analyses (no replication), and replicated benthic infaunal analyses. Sediments from all ten stations were tested with one type of bioassay.

The study results supported the initial hypothesis. The Sediment Quality Triad provided an integrated assessment of pollution-induced degradation which could not have been done with any of its component parts independently. Sediment chemistry measurements indicated that the Islais Waterway site was much more contaminated by a number of substances than the site near Oakland, while the latter was slightly more contaminated than the site in San Pablo Bay. Although even the highest sediment chemical concentrations measured in Islais Waterway were much lower than maximum concentrations of similar compounds measured in other areas of the West Coast where sediment toxicity and modified infauna were observed, they were similar to the minimum levels at which some effects have been observed in Puget Sound. As a result the chemical data by themselves would not have indicated that major environmental effects were predictable. Analyses of benthic infaunal community structure indicated that all three sites were altered compared to the infauna in two other West Coast areas. However, San Francisco Bay is a shallow estuary and some differences between communities in the Bay and coastal or fjord environments are expected. The Islais Waterway site was the most altered while the Oakland site was slightly less altered than the San Pablo Bay site. However, there were substantial sediment texture differences that could have explained the faunal differences observed between the three sites. If sediment chemistry and toxicity data had not been collected, the faunal between-site differences could have been attributed to only the texture differences. Sediment bioassays indicated that the Islais Waterway site sediments were most toxic, the San Pablo Bay site sediments were least toxic, and the Oakland site sediments were intermediate. Taken alone, the bioassay data would have predicted that the degree of contamination at the Islais Waterway site was greater than actually measured. Thus the full complement of Triad responses at the three sites were not predictable using data from only one of the Triad components; the same lack of predictability was observed for the stations within each site.

The Sediment Quality Triad provided the information necessary to determine the presence and measure the degree of contamination and of synoptically measured biological effects at each station and site. These measures of contamination and biological effects, together, were used to assess the overall degree of degradation of each station and site. Islais Waterway was the most pollution-degraded site, and using a composite index developed from the three Triad components, could be considered to be 58X more degraded than the San Pablo Bay site, the site most removed from direct anthropogenic influences. By the same index, the Oakland site was 1.4X more degraded than the San Pablo site.

On the basis of the present study, the Sediment Quality Triad is recommended for incorporation into the NOAA National Status and Trends (NS&T) Program. The NS&T Program presently includes analyses for a relatively comprehensive list of chemicals in sediments. However, the San Francisco Bay data, in which relatively high degrees of bioeffects were measured relative to the chemistry data, suggest that the NS&T analytical window may be too narrow to include all chemical contaminants capable of causing toxicity. Bottomfish histopathology determinations, which are currently the only bioeffects component of the NS&T Program, are not site-specific because these fish are highly motile. Thus, in contrast to sediment bioassays and measurements of infaunal community structure, bottomfish histopathology data cannot be directly related to sediment chemistry measurements at a particular station or site. We recommend that, as a minimum, sediment bioassays and some type of inexpensive benthic infaunal analysis be added to the NS&T Program measurements. The use of multiple bioassays is recommended to allow for differential toxicity to different organisms and life-history stages. Two specific bioassays are recommended: sensitive amphipod lethal and sublethal tests, and bivalve larvae lethal and sublethal tests. Ideally benthic infaunal community structure measurements with species-level taxonomy should also be included in the NS&T Program to complement the bioassays. However, given the relatively high cost of these analyses, and the difficulties in comparing inherently different communities among geographic areas, we recommend incorporation of one of the four less expensive options offered in Section 4.4.2. Specific recommendations for the presentation and use of the Sediment Quality Triad are provided in Section 4.4 of this report.

The chemicals measured in San Francisco Bay included all compounds measured in sediments by the NS&T Program, with the exception of microbial tracers of sewage. Chemical substances with potential toxicity that were particularly elevated in San Francisco Bay sediments, and which were considered to be of anthropogenic origin, are: lead, mercury, tin, silver, the low and high molecular weight aromatic hydrocarbons, DDTs and PCBs. Maximum levels of some of these compounds in Islais Waterway approached or exceeded apparent threshold levels for biological effects as determined in Puget Sound (Washington State) sediments.

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1.0 INTRODUCTION

The National Oceanic and Atmospheric Administration (NOAA) is authorized to conduct a broad range of marine environmental research and development studies. In partial fulfillment of its mandates, NOAA has initiated the National Status and Trends (NS&T) Program to determine the status of contamination in many coastal and estuarine areas and trends in the levels of contamination. Thus far the NS&T Program is based largely upon chemical analyses of sediments, bivalves and flatfish. A need has been seen by NOAA to augment the Program with a variety of biological measures to provide some perspective to the chemical data. One initiative to satisfy this need has been the development of a sediment quality index based upon the concept of a triad of measures, the Sediment Quality Triad (Long and Chapman, 1985; Chapman, in press a). The Triad consists of measures of sediment contamination, toxicity and resident infauna community structure. Preliminary testing of this concept has been conducted in Puget Sound, Washington State, using a broad range of available data (Chapman et al., 1985a). Despite problems of data incompatibility, the results were encouraging.

The present study was initiated as a field trial to better determine the applicability of the Sediment Quality Triad concept to the NS&T Program. The field trial was conducted in San Francisco Bay in 1985. In addition to testing the Triad concept, this study was intended to provide data complementary to that of the NOAA NS&T Program (initiated in 1985) for the San Francisco Bay system.

The Sediment Quality Triad is intended to incorporate three essential components to define pollution-degraded areas: measurements to determine that anthropogenic contamination is present (i.e., bulk sediment chemistry), measurements that demonstrate that substances in the sediment can interfere with the normal functioning of at least some biological organisms tested in the laboratory (i.e., sediment bioassays), and assessment of in situ alteration of resident biological communities (e.g., measures of benthic infaunal community structure). Individually, each of these components can probably only provide part of the answer to the question of whether an area is subject to pollution-induced degradation. Pollution-induced degradation is defined as a biologically damaging excess of contamination involving a threat to human life, harm to living resources, or some other deleterious effect. Chemical measurements can readily determine the degree of contamination, but such data would not be expected to provide information on whether this contamination is having any effect on biological organisms. Sediment bioassays measure toxicity (both lethal and sublethal endpoints) and are intended to indicate whether sediments contain substances capable of harming biological systems, but they are measures performed under worse-case laboratory conditions and cannot be expected to fully assess in situ effects on resident populations. In contrast, while in situ measurements of resident populations can identify areas where conditions are altered from their "natural" state, they generally provide only limited information regarding the cause(s) of the alteration. These populations can be altered by a wide variety of non-anthropogenic variables.

Measurements of pollution-induced degradation would be greatly facilitated if any one of the above Triad components was sufficient to define problem areas. For instance, if sediment chemical concentrations that were universally toxic could be defined for all chemicals and combinations of chemicals, or if bioassay results could be reliably related to *in situ* impacts, or if population ecology could identify alterations in populations that were absolutely due to chemical contamination, then an integrated assessment such as the Sediment Quality Triad would be unnecessary. The hypothesis tested in the present study was that none of these individual measures presently suffices to define pollution-induced degradation and as a consequence, only through measurement of all three components of the Sediment Quality Triad and examination of the preponderance of evidence can "problem" areas be identified. The criterion for accepting the hypothesis was that no individual component of the Triad could be used consistently and with the same degree of accuracy to predict the behavior of the other two Triad components.

1.1 Objectives

The overall objective of this study was to evaluate the utility of the Sediment Quality Triad for use in the NS&T Program through the performance of a full field trial in San Francisco Bay. The specific objectives were:

a. To collect, composite, homogenize and aliquot surficial sediments from thirty stations, ten stations from each of three sites in San Francisco Bay reflecting high, moderate and low degrees of chemical contamination.

b. To conduct detailed sediment chemistry analyses for samples from each of nine stations, three stations from each of three sites, and archive the remaining samples.

c. To conduct detailed sediment toxicity bioassays, using both lethal and sublethal tests, on samples from each of the nine stations used for chemistry analysis, and to test the toxicity of the remaining 21 samples with an acute lethality bioassay.

d. To conduct detailed (species-level) benthic infaunal analyses of sediments from each of the nine stations, and archive the remaining samples.

e. To evalute a variety of approaches to combining chemistry, toxicity and infaunal data in the Sediment Quality Triad to determine the degree of degradation of each station and each site.

f. To provide NOAA with specific recommendations for using the Sediment Quality Triad approach in the National Status and Trends Program.

2.0 METHODS

2.1 Geographical Study Area

The present study was designed to conduct biological and chemical sampling at three sites in San Francisco Bay. San Francisco Bay was chosen for this study for several reasons: it is an area which has not been definitively studied, it is an extremely important West Coast estuary, and it is presently included in the NS&T Program thus allowing intercomparison of data from this study with forthcoming NS&T data. Sites were chosen based on best available information to represent presumably low, moderate and high levels of chemical contamination. Sites chosen, in order of presumed increasing anthropogenic influences, were: San Pablo Bay (SP), off Oakland (OA) and Islais Waterway (IS) (Fig. 1). Ten stations were established for each site, within an area of 1 km2 (Fig. 2).

The site selected in San Pablo Bay was an open water site located in the southern part of the Bay, roughly 2500 m from the nearest shore and just southwest of a navigation channel marker buoy. Samples were collected to the west of the shipping channel. The Oakland site was also located in open water, immediately south of the Oakland Inner Harbor Entrance Channel, and about 250 m offshore. The Islais Waterway site was a partially dredged waterway. Samples were collected along the margins of the dredged channel in areas generally affected by Combined Sewer Overflow (CSO) discharges (CH2M-Hill, 1979).

Precise station location information (e.g., water depth, position relative to shore facilities) is presented in Appendix A.

2.2 Approach

Ten stations were sampled in each of the three sites for sediment bioassay testing, benthic infaunal analyses and sediment chemistry determinations. Sediment samples from all thirty stations sampled were subjected to amphipod (Rhepoxynius abronius) sediment bioassays. Otherwise, only sediments from three stations (02, 05 and 09) in each site were analysed with the full complement of Triad measures. Sediments and benthos from the other seven stations at each site were archived after collection. At each of the nine stations (three from each of San Pablo Bay, Oakland and Islais Waterway) whose sediments were fully analysed, the following determinations were made:

1. Detailed chemical analyses were made on composited surface sediments, aliquots from which were also used for bioassay testing.
2. Four separate types of sediment bioassays were conducted on the composited surface sediment.
3. Benthic infauna were identified and enumerated for each of five grab samples from each of these stations. The benthos grabs were collected independently from those grabs composited and used for sediment chemistry and bioassay.

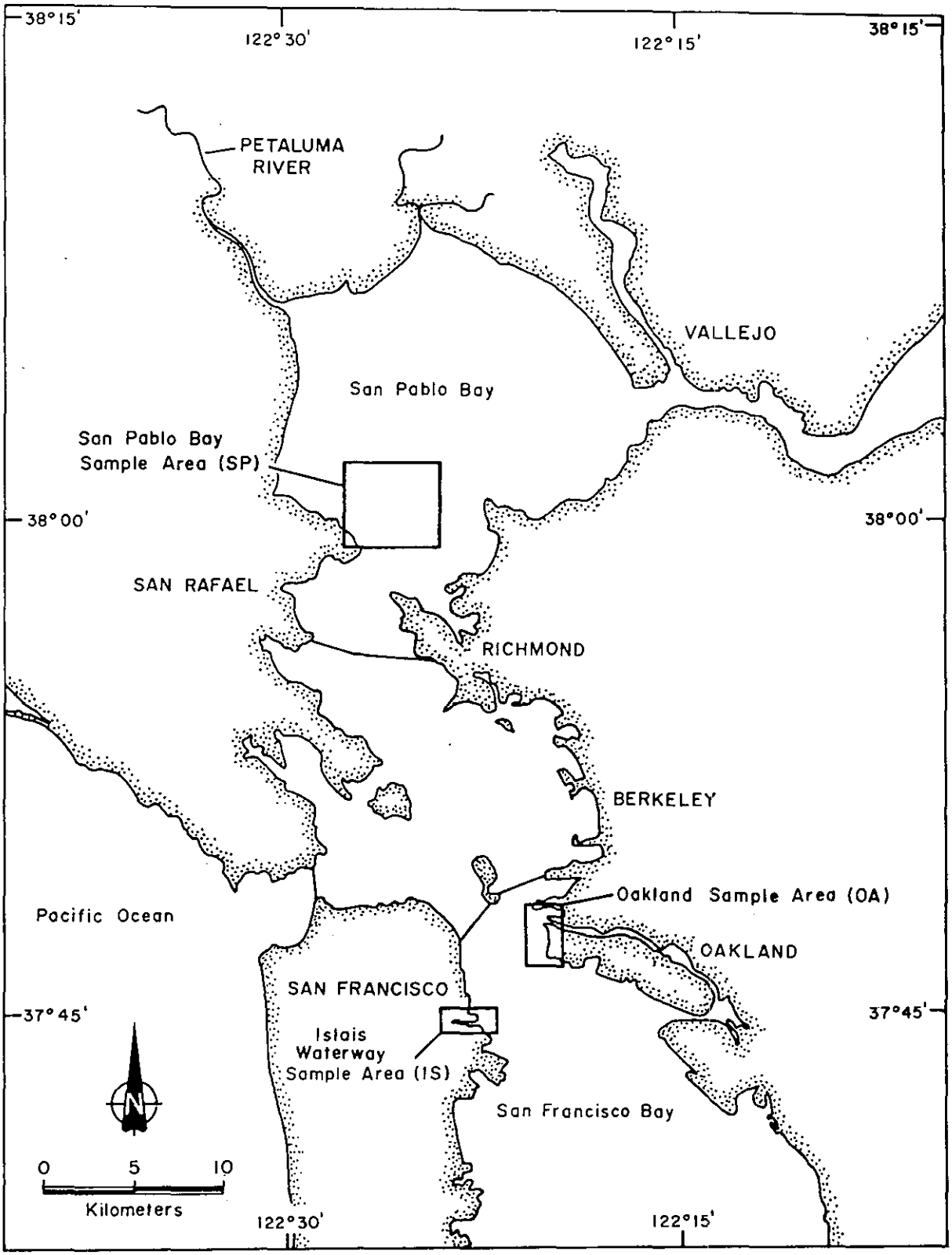


Figure 1. Map of San Francisco Bay showing general areas sampled.

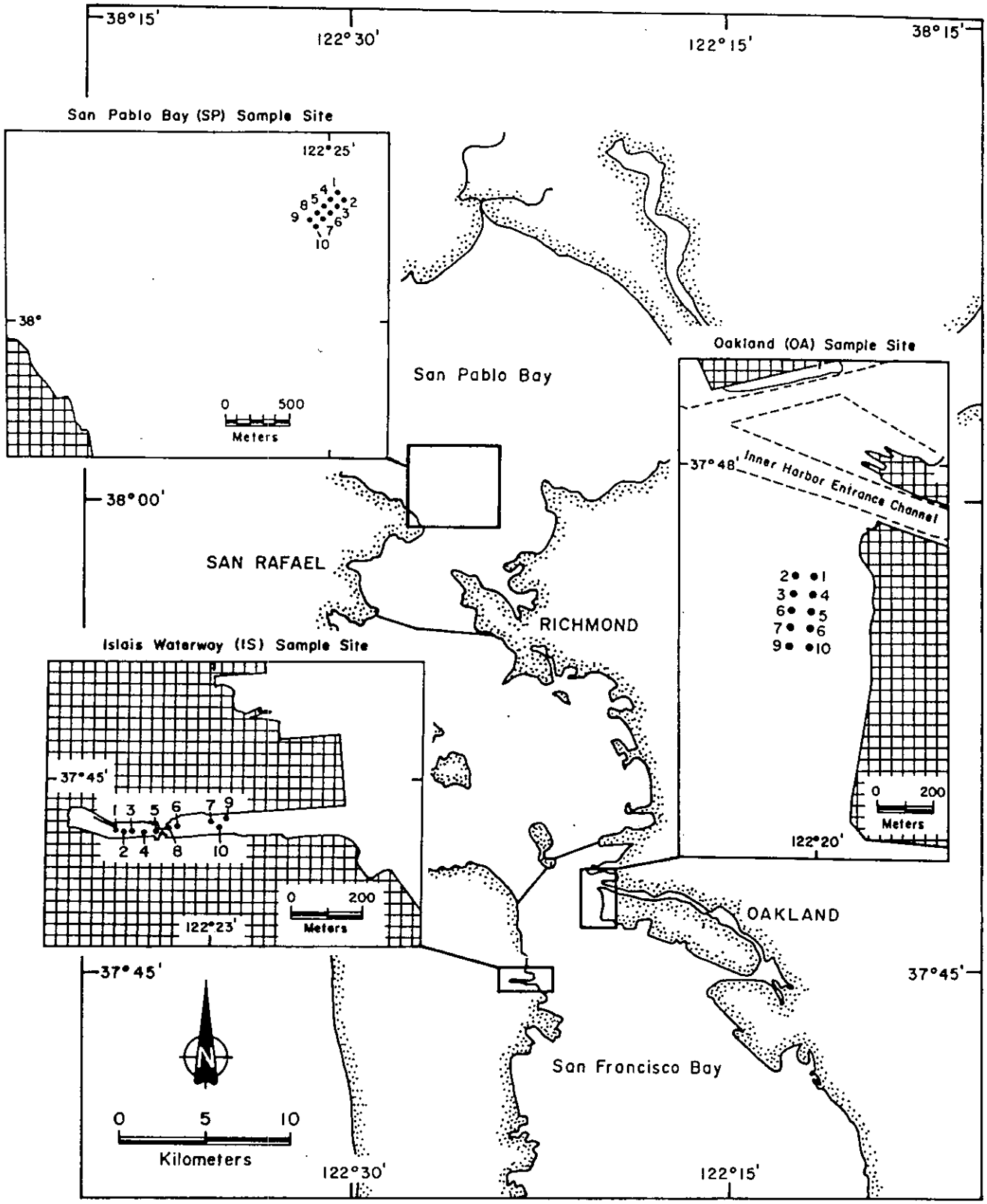


Figure 2. Locations of sampling stations within sites sampled.

Sediments collected at the remaining seven stations from each site for chemical analysis and benthic infaunal determinations (Stations 01, 03, 04, 06, 07, 08, 10) were archived for possible future use, the former by freezing and the latter by preservation. Sediment from these stations was not archived for possible future bioassay testing as standard methods of archival, including freezing, have been shown to alter sediment toxicity (U.S. EPA, 1984a). Instead, sediment toxicity was determined for all of these 21 stations, using fresh sediments and a single test, the amphipod bioassay discussed in Section 2.5.1.

The results of the present analyses were used to classify the expected degree of degradation (i.e., alteration of the resident biota by pollution) of each station and each site, based on both individual measures (i.e., sediment chemistry, bioassay results and infauna characteristics) and combined measures (i.e., the Sediment Quality Triad). Specific recommendations were then made regarding the application of the Sediment Quality Triad to NOAA's National Status and Trends Program.

2.3 Sediment Collection

2.3.1 Station locations

Samples were collected from the three sites in San Francisco Bay shown in Figure 1. At each site, 10 stations were occupied (Fig. 2). At the San Pablo Bay (SP) and Oakland (OA) sites, the 10 stations were laid out in two parallel grids of five stations with each station being 100 m from the others. The station tracks were linear but roughly followed the bottom contours. At the Islais Waterway (IS) site, the 10 stations were placed along the axis of the waterway. Because the sediments at a number of locations in Islais Waterway where sampling was attempted were not suitable for the purposes of this study (i.e., water depths too great, substrate too coarse, or the bottom slope too steep for good sampling), the stations in Islais Waterway were not sampled in precise numerical order from the head of the waterway toward the mouth. At all locations, the sampling depths were between 6 and 12 m. Station and sampling information are described on the log sheets included in Appendix A.

2.3.2 Sampling procedures

Sediment samples at all stations were collected with a 0.1 m^2 modified Van Veen grab with top doors that opened to allow easy access to the surface of the sediments in the grab. The grab was operated in the normal manner. At each station, grabs were designated in a roughly consecutive sequence for benthic infauna and for chemistry/bioassays, as described below, to attempt to obtain comparable, synoptic data. Precise sampling sequences were recorded.

Upon retrieval aboard ship, the upper flap was opened and the contents examined to ensure that adequate penetration had been achieved and that no leakage or surface disturbance had occurred. The contents were examined and field notes of penetration, color,

odor, texture and other noteworthy characteristics, (e.g., the presence of organisms or debris) were recorded on the station log sheets (Appendix A).

For the benthic infaunal samples, the entire contents of the grab, including the overlying water, were placed in a large plastic bucket then transferred in smaller quantities to smaller buckets that had a 1 mm stainless steel screen replacing the normal bottom. The sediment was sieved through the screens using a gentle stream of unfiltered seawater supplied by the ship's pump or by immersing the bucket in and out of the water over the side of the vessel. The residues remaining on the screens were gently washed down, placed in polyethylene bags and preserved with 10% buffered formalin. Five replicate grabs were collected for infauna at each of the 10 stations for each of the three sites.

For the chemistry and bioassay samples, the grab contents were examined as described above prior to processing, then the surface water was carefully decanted to expose the undisturbed sediment surface. The upper 2 cm of sediment (i.e., recently deposited materials) were carefully removed with a stainless steel spatula and transferred to a stainless steel bowl. When sufficient sediment had been collected from a station, the contents of the bowl were homogenized with a stainless steel spoon until no color or textural differences could be detected. The homogenized sediments were then transferred to the sample containers.

At the three stations at each site where immediate chemical analyses and the entire suite of bioassays were to be performed, a minimum of 5 liters of sediment were transferred to new polyethylene bags and stored on ice for the bioassays and 1 liter of sediment was placed in a precleaned glass jar with a teflon cap-liner for chemical analysis. An additional 20 gm of sediment was placed in polyethylene jars with preservative for the analysis of sulfides. At the remaining seven stations at each site, 1 liter of sediment was collected in a polyethylene bag for the bioassays and 500 mL were placed in precleaned glass jars with teflon cap liners for archival and possible future chemical analyses. Samples for bioassay and chemical analyses were kept and shipped in coolers with ice, and were received at the laboratories within 4 d of collection. Chemical samples for archival were frozen immediately upon receipt at the analytical laboratory.

Prior to sampling at each station, the grab was thoroughly rinsed with site water. The spatulas and bowl were rinsed with site water and with pesticide grade dichloromethane and then covered with aluminum foil.

2.4 Sediment Characterization

The list of parameters analysed in the sediments collected in San Francisco Bay are listed in Table 1, together with the detection limits for the procedures. The chemical analytes are those specified by NOAA for the NS&T Program. The analytical methods for each parameter are discussed below.

Table 1. List of parameters measured in San Francisco Bay sediments

	Detection Limit (ug/dry Kg)[a]		Detection Limit (ug/dry Kg)[a]
Conventionals		High Molecular Weight	
Grain-size	n/a	Aromatic Hydrocarbons[b]	
Total Organic Carbon	n/a	Benzo(a)pyrene (BAP)	8
*Total Volatile Solids	n/a	Benz(e)pyrene (BEP)	8
*Sulfides	500	Benz(a)anthracene (BAA)	10
*Total Solids	n/a	Chrysene (CHR)	10
*Electrode oxidation-reduction Potential (Eh)	n/a	Dibenzanthrancene (DBA)	16
		Fluoranthene (FLA)	4
Major Elements		Pyrene (PYR)	4
Aluminum (Al)	1.2		
Silicon (Si)	1.2	Other Hydrocarbons	
Manganese (Mn)	0.3	Biphenyl	4
Iron (Fe)	1.2	Perylene	4
*Magnesium (Mg)	0.2	Coprostanol	10
*Calcium (Ca)	0.7		
*Sodium (Na)	8.0	Chlorinated Hydrocarbons	
Titanium (Ti)	0.3	Aldrin	0.08
		alpha-Chlordane	11.0
Trace Elements		*trans-chlordane	14.0
Antimony (Sb)	5.0	op'-DDD	0.14
Arsenic (As)	0.6	op'-DDE	0.25
Chromium (Cr)	0.5	op'-DDT	0.14
Copper (Cu)	0.6	pp'-DDD	0.15
Cadmium (Cd)	0.2	pp'-DDE	0.08
Lead (Pb)	0.3	pp'-DDT	0.10
Mercury (Hg)	0.02	Dieldrin	0.12
Nickel (Ni)	2.0	Endrin	0.13
Selenium (Se)	0.4	Heptachlor	0.12
Silver (Ag)	0.3	Heptachlor expoxide	0.12
Tin (Sn)	2.2	Hexachlorobenzene	0.12
Thallium (Th)	0.3	Lindane	0.16
Zinc (Zn)	0.3	Mirex	0.12
		trans-Nonachlor	0.08
Low Molecular Weight		Polychlorinated biphenyls (PCBs)	2.5
Aromatic Hydrocarbons[b]			
Acenapthene (ACE)	4		
Anthracene (ANT)	4		
Naphthalene (NPH)	4		
1-methylnaphthalene (1MN)	4		
2-methylnaphthalene (2MN)	4		
2,6-dimethylnaphthalene (26D)	4		
2,3,5-trimethylnaphthalene (235)	4		
Fluorene (FLU)	4		
Phenanthrene (PHN)	4		
1-methylphenanthrene (1MP)	4		

a. The detection limits are the instrumental estimates. Actual detection limits may be higher due to matrix effects.
b. Acronyms (in parentheses) are as used in Figures 10, 12, 13, 14.
* Parameters not analysed by the NOAA National Status and Trends (NS&T) Program; the only parameter analysed by the NS&T Program but not included here is a microbial indicator of sewage contamination.

2.4.1 Conventional parameters and elemental analyses

The analytical procedures used for the determination of grain size, total organic carbon, total volatile solids, sulfides and the elements were all based on standard methods and are thus only briefly reviewed below.

Sediment grain size was determined by ASTM Method D 422-63, involving sieving of the larger (sand) fraction and sedimentation of the finer materials (silts and clays) (ASTM, 1985a). Total organic carbon (TOC) was determined on each sample by high temperature combustion in pure oxygen with the carbon dioxide produced being measured in a colorimetric titration using a Coulometrics, Inc., Carbon Dioxide Coulometer (Weyerhaeuser, 1985). Total volatile solids (TVS) were determined by first drying the sample at 103oC (which also determined the percent solids) followed by measuring the weight loss after high temperature (550oC) combustion (APHA, 1985). Grain size, TOC and TVS were reported as percentages of sediment dry weight. Sulfides were measured using distillation into zinc acetate followed by colorimetric reaction with methylene blue with the determination of absorbance at 650 nm (EPA/CE, 1981). Electrode potential (Eh) was measured during the amphipod sediment bioassays as described in Section 2.5.1. Elemental composition was determined using the standard EPA Contract Laboratory protocol involving inductively coupled plasma emission measurements or acid digestion of the sample (Eggiman and Betzer, 1976) and measurement of the dissolved elements by atomic absorption, as appropriate (U.S. EPA, 1984b).

2.4.2 Organic compounds

Organic compounds including coprostanol were analysed using methods similar to MacLeod et al. (1984), involving a variation of EPA standard method 1625 (U.S. EPA, 1984c). A short outline of the procedure follows.

Wet sediment (100 g) was weighed directly into a Soxhlet thimble, then 5 ug of radio-labeled base/neutrals and 20 ug labeled acids were added to the sediment. Methanol was added to the receiving flask and to the thimble, the sediment and methanol stirred, and the methanol allowed to cycle. At the first cycle the proportion of water in the extract made it difficult to continue cycling methanol. The extracting solvent was changed to 2:1 methylene chloride:methanol and the Soxhlet extraction was continued for 12-16 h. The Soxhlets were opened and the samples stirred during the extraction step to reduce channeling.

Half-saturated aqueous sodium sulfate was added to the combined Soxhlet solvents and extracted under acidic conditions with methylene chloride. The extracts were combined, and Kuderna-Danish concentrated. At this step, it was found that there was still excess methanol in the extract, and it was washed with acidic water, dried with sodium sulfate, and reconcentrated by Kuderna-Danish. The extract was shaken with mercury for at least 12 h to remove elemental sulfur. The methylene chloride extract was centrifuged and the supernate was filtered through a glass fiber filter to eliminate

mercuric sulfide. The extract was evaporated under nitrogen to one mL and run through Biobeads SX-3 using methylene chloride as eluent. The fraction containing the priority pollutants was collected, Kuderna-Danish concentrated to ten mL, and one mL was removed for chlorinated hydrocarbons, PCB and pesticide analysis. The solvent was exchanged to methanol for the remainder of the extract.

The methanolic solution was passed through a short octadecyl column and the solvent exchanged into methylene chloride while concentrating to 0.5 mL. The methylene chloride solution was transferred to a vial and stored refrigerated until gas chromatography/mass spectrometry (gc/ms) analysis. Before analysis, difluorobiphenyl internal standard was added.

The one mL methylene chloride extract removed for chlorinated hydrocarbon, PCB and pesticide analysis was exchanged into hexane and the extract passed through a 7% deactivated alumina column. The collected fraction was spiked with decafluorobenzophenone and decachlorobiphenyl as internal standards, transferred to vials, and stored refrigerated until analysis by dual column capillary gas chromatography/electron capture (gc/ec).

2.4.3 Quality assurance/quality control (QA/QC)

The QA/QC program followed the recommendations of Keith et al. (1983). For the conventional parameters and elements this involved the appropriate use of analytical standards and method and reagent blanks as specified in the standard protocols.

Because of the difficulty of performing accurate analyses of organic compounds and the questions that often arise regarding their quality, an extensive QA/QC program was established for these compounds, as follows.

Aromatic hydrocarbons and coprostanol - Five calibration standards were prepared from sealed ampoules of purchased mixtures of priority pollutants. The standards ranged from 0.4 to 25 ug/mL. The target compounds were purchased from Supelco (Supelpreme) and mixtures of isotope labeled compounds were purchased from MSD Isotopes. New solutions of target and labeled compounds were prepared from these mixtures specifically for this set of analyses. Responses of the labeled compounds to difluorobiphenyl (internal standard) and of the target to the labeled compounds were used to create a compound library response list. The calibration curves were sufficiently linear that the average response from the response list could be used to calculate compound amounts. The mass spectrometer was calibrated and an on-going calibration verification standard injected daily. Compounds were searched for and quantified with "TCA," a program available from Finnigan-MAT for the analysis of target compounds. Results generated by the program were checked as outlined below.

All samples were spiked with labeled compounds at 5 ug base/neutrals and 20 ug acids to monitor method performance. To establish the ability of the laboratory to generate acceptable precision

and accuracy for priority pollutants in sediments, four blank spikes were taken through the entire procedure with the exception of the methanol Soxhlet extraction step. Base/neutrals were spiked at 8 ug and acids at 20 ug. Using the results of this set of four analyses, the average recovery and standard deviation of the recovery was calculated for each compound. The precision and accuracy results were well within the precision and accuracy acceptance criteria for EPA method 1625.

In addition, a blank spike was run through the procedure during this series of analyses. The results for each sample, blank, and spike were reviewed manually. Recovery of the labeled compounds for all samples, blanks, and spikes were monitored to determine if the target compounds were adequately recovered for quantification. The spectra of target compounds found were examined to determine if they matched library spectra. When labeled compounds were missed by the processing program, the label and the target were searched for and either added to the quantitation list or calculated manually using the same formula which would have been used by the TCA program.

Chlorinated hydrocarbons - The following procedures were employed to provide precise and accurate gas chromatography analysis, while keeping the analysis time minimal: the application of dual column/dual detector high resolution gas chromatography, and multiple internal spikes in experimental design and data reduction.

A four-point calibration curve was generated for the pesticides. Before gc/ec analysis two internal standards, decafluorobenzophenone and decachloronaphthalene were added. Least squares analysis was performed on the retention time using the PCB isomer internal standards as references and these data were used to predict the retention time for the compounds. All amounts were calculated using decachlorobiphenyl as the internal standard. Retention time windows were calculated from experience with the injection of standards.

Samples, blanks and spikes were analysed by dual column capillary gc/ec. The columns were of different phases (DB1701 and DB1) to allow simultaneous second column confirmation of "detected" compounds. If a compound was detected within the correct retention window on both columns, it would be reported.

Using dual column/dual detectors provided much more information than conventional methods. Besides the obvious retention time confirmation provided by two different polarity columns per single injection there was also the response confirmation by calculating ratios between the two detectors. If there was confirmation by retention time but the response differed, then there was a coeluting compound on one of the columns. Single column methods of analysis do not take into account coeluting compounds - resulting in false positives or larger values. With the multiple internal spikes and least square analysis, cross validation was provided even on the quantitation reference compound.

Precision and accuracy were greatly enhanced by the use of multiple internal spikes, which were used for checks on recovery during extraction and on instrument health during gc analysis. They also provided precise modeling of retention time by supplying "during-analysis" markers. Through least square analysis, accuracies in concentrations of 100 parts per million (0.01%) were realized on the sediment samples.

Reference sample analysis - In addition to the above procedures, a sample of reference sediment prepared by the NOAA National Marine Fisheries Service (NMFS) National Analytical Facility (D. Brown, Seattle) was analysed as part of this effort. The sediment consisted of natural marine sediment from a polluted estuary, the Duwamish River, Puget Sound, Washington. The results of the analysis of this reference material were generally slightly higher than those reported by NMFS, but the values for all of the organic compounds of interest agreed to within a factor of two of the comparable values reported by the NMFS facility (D. Brown, NMFS, pers. comm.; Appendix B). This comparison, which was conducted because NMFS are performing sediment chemistry analyses for part of the NS&T Program and are also conducting some of the programmatic QA/QC tasks, indicates that the chemical data obtained in the present study should have a high degree of comparability with the results of sediment chemistry measurements for the NOAA National Status and Trends Program.

2.5 Toxicity Testing

Field-collected sediments typically contain a complex mixture of chemicals, depending on local sources. There is rarely any single chemical that can be identified as causing toxic responses observed in the laboratory or the field, nor are all potentially toxic chemicals measured. In addition, different organisms will respond differently to different types or combinations of chemical contaminants in sediments (Swartz et al., 1982; Chapman et al., 1985b). In order to provide a realistic assessment of sediment toxicity, more than one bioassay test is required as different sediment bioassays may reveal toxicity not seen by other tests. Ideally, a range of tests should be used including lethal, sublethal and reproductive impairment tests (Chapman and Long, 1983).

In order to meet these needs, four separate sediment bioassay tests were used to measure toxicity of sediments from the nine stations for which chemistry and benthic infauna were determined. Tests were chosen to signal toxicity over a wide range of taxa and biological processes. The Rhepoxynius abronius 10-d test developed by Swartz et al. (1982, 1985a) was used to measure acute lethality. This test also has a sublethal component (avoidance of the sediments) and test results can be related to the distributions of sensitive amphipods in situ. The 48-h mussel (Mytilus edulis) larvae test described by Mitchell et al. (1985) for use in solid waste testing was used to measure sublethal effects. This test also has an acute lethal component (death of the larvae). Behavioral effects were measured by determining the rate of reburial of the clam Macoma balthica using techniques developed by McGreer (1979). Test results can be related

to field distributions of Macoma. Reproductive impairment was measured by determining copepodite production by the harpacticoid copepod, Tigriopus californicus, using methods developed by Misitano (1983).

The R. abronius 10-d test was also used to measure the toxicity of the 21 stations for which chemistry and infauna samples were archived but not analysed.

Quality assurance/quality control (QA/QC) procedures used for bioassay testing followed those outlined by ASTM (1985b) and APHA (1985). All bioassays were conducted using negative (clean) controls. Only healthy organisms of similar size and life history stage were used in the bioassays, and all taxonomic identifications were confirmed by qualified taxonomists. All bioassay containers were randomized and testing was conducted without laboratory personnel knowing sample identities. Water quality conditions were maintained (and periodically checked) such that undue stress was not exerted on the bioassay organisms unrelated to the test sediments. Standard laboratory procedures were followed in all testing. Procedures employed by E.V.S. Consultants for the R. abronius 10-d test have been verified by inter-laboratory calibration (Mearns et al., in press).

2.5.1 Amphipod bioassay

The sediment bioassay with the amphipod Rhepoxynius abronius has been used extensively in recent years to determine the acute lethality of field collected sediments (e.g., Swartz et al., 1981, 1982, 1985a, b; Chapman et al., 1982, 1984, 1985b; Williams et al., in press). This amphipod species is a sensitive indicator of contaminated areas both by its absence in natural populations from such areas (Swartz et al., 1982, 1985b; Chapman et al., 1985a; Long and Chapman, 1985), and by its response to field collected and spiked contaminated sediments in laboratory studies (Swartz et al., 1985a).

The infaunal amphipod Rhepoxynius abronius was collected subtidally from West Beach, a relatively remote site on Whidbey Island (Washington State), using a bottom trawl. Amphipods were maintained and transported in clean coolers with ice, and were returned to the E.V.S. Consultants laboratory within 18 h of collection.

Following their arrival in the laboratory, amphipods were kept in holding containers filled with fresh seawater (28 ppt salinity) and maintained at 15 $\pm$ 1oC under continuous light until used in testing. Cultures were aerated but not fed during acclimation and were held for five days prior to testing. Prior to testing, amphipods were hand sorted from sediments and identifications were confirmed using a Wild M5 dissecting microscope. Damaged, dead or unhealthy individuals were discarded.

Acute lethality of whole fresh (unfrozen) sediments was measured by the methodology of Swartz et al. (1982, 1985a), which involved a 10-d exposure to test sediments. A 2 cm layer of test sediment was placed in 1 L glass jars and covered with 800 mL of clean seawater (28 ppt salinity). The beakers were then covered with

clean glass petri dishes. The interstitial salinities of all test containers were measured after seawater addition and found to be 27 ± 2 ppt. Each beaker was seeded (randomly and blindly) with ~20 amphipods and aerated. Six replicates (20 amphipods each) were run per station. Five beakers were used to determine toxicity, while the sixth beaker served as a reference for daily measurement of water chemistry (pH, DO, salinity, temperature). Containers were checked daily to establish early trends in mortality and sediment avoidance, and also to gently sink any amphipods which had left the sediment overnight and become trapped by surface tension at the air/water interface. A negative (clean) control sediment (from West Beach, the amphipod collection site) was run concurrently with the test sediments.

Bioassay tests were terminated after 10 d when sediments were sieved (0.5 mm screen), and live and dead amphipods removed and counted. Amphipods were considered dead when there was no response to physical stimulation and microscopic examination revealed no evidence of pleopod or other movement. Missing amphipods were assumed to have died and decomposed prior to the termination of the bioassay (Swartz et al., 1982, 1985a).

Amphipod avoidance response was also determined from daily counts of numbers of amphipods that had emerged from the sediments. Data were pooled at the end of the 10 d exposure period to calculate means and standard deviations. These results were compared with amphipod survival in sediments.

In addition to the above analyses, the oxidation/reduction potential (Eh) of the sediments was measured in test beakers at sediment depths of 0 (surface), 1 and 2 cm at Day 0, just prior to amphipod exposure. Surface Eh measurements were conducted again on Day 10 just prior to bioassay termination. Only surface Eh measures were taken at the time to avoid crushing those amphipods burrowed in the sediments.

Any significant differences between test sediments was determined by analysis of variance. Differences in mean survival and avoidance between test and control sediments were determined by Dunnett's procedure (Miller, 1966) and Duncan's multiple range test (Steel and Torrie, 1960; Dowdy and Wearden, 1983). One-tailed Dunnett t-tables were used to determine if mean survival was significantly less and mean avoidance was significantly greater in each test series than control values.

2.5.2 Mussel larvae bioassay

Partial life-cycle tests with mussel larvae measure both survival after a 48 h exposure of developing embryos to sediments, and the induction of abnormal development. Significant mortalities and abnormalities compared to controls are indicative of chemical toxicity effects (ASTM, 1985b). The bivalve embryo bioassay technique, described in Standard Methods (APHA, 1985) and ASTM (1985b) has proved to be a rapid and reliable indicator of environmental

quality. Marine bivalve embryos and larvae are more sensitive to contaminants than the adult of the same species (Bryan, 1971; Calabrese et al., 1973; Hrs-Brenko et al., 1977; Calabrese, 1984).

Adult bay mussel stocks (Mytilus edulis) were collected from Woodlands, Indian Arm, British Columbia. Prior to spawning, mussels were scraped free of adherent (fouling) organisms and stored moist at 5oC for 24 h. Bioassay procedures are discussed by Mitchell et al. (1985) and followed those developed by Chapman et al. (1983) and Chapman and Morgan (1983) for oyster larvae.

Spawning was induced by placing the chilled mussels in individual Pyrex dishes containing 250 mL of 5 um filtered, UV-sterilized seawater at 22oC. Female and male mussels began to produce gametes after about 60 min and were allowed to spawn for 30 min before being removed from the spawning dishes. Fertilization was accomplished within 1 h of spawning initiation by combining eggs and sperm in a 1 L Nalgene beaker. The fertilized eggs were then washed through a 0.25 mm Nitex screen to remove excess gonadal material and suspended in 2 L of filtered, sterilized seawater at incubating temperature. The embryos were kept suspended prior to testing by frequent agitation with a perforated plunger. When microscopic examination of fertilized eggs revealed the formation of polar bodies, egg density was determined from triplicate counts of the number of eggs in 1.0 mL samples of a 1:99 dilution of homogeneous egg suspension.

Sediment bioassays were conducted in clean (rinsed with 5% nitric acid) 1 L plastic bottles. Twenty grams (wet weight) of the appropriate sediment was added to each bottle and volume brought up to 1 L with filtered, sterilized seawater (28 ppt salinity) to make a final concentration in all containers of 20 g (wet weight) of sediment per liter of seawater. All tests were performed with five replicates per station. The sediment controls contained 20 g/L of clean sediment (from off West Beach, Whidbey Island, the collection site for the sensitive amphipod Rhepoxynius abronius). Seawater controls (no sediment added) were also tested to determine the effects of the clean sediment on larval survival and abnormality.

The sediments were suspended by vigorous shaking for 10 seconds, then the embryos were added and the suspended sediments allowed to settle. No additional agitation was provided.

Within 2 h of fertilization, each container was inoculated with approximately 20,000 developing mussel embryos to give a concentration of about 20 per mL. The containers were covered and air-incubated for 48 h at 19 $\pm$ 1oC under a 14 h light:10 h dark photoperiod. Test vessels were not aerated during the bioassay. After 48 h, larvae were concentrated by decanting the contents of the test vessels through a 38 um sieve. The bottom sediments were not sieved as bivalve larvae are pelagic and do not associate with the benthos until much later in their life-cycle, when metamorphosis occurs. The larvae were washed into a 100 mL graduated cylinder and diluted to a volume of 100 mL. Repeated mixing with a perforated plunger was used to ensure that the larvae were homogeneously suspended prior to

removal of a 7.25 mL aliquot for larval enumeration. The larvae were preserved in 8 mL screw-cap glass vials in 5% buffered formalin. The preserved samples (equal in volume to that containing 300-500 larvae in controls) were examined in Sedgewick-Rafter cells under 100X magnification. As bivalve larvae sink after preservation (ASTM, 1985b), 75% of the water was discarded from the vials before examining the residual volume containing the larvae. Quality assurance procedures included independent (blind) counts.

Normal and abnormal prodissoconch I larvae were enumerated to determine percent survival and percent abnormality. Percent survival in the test solutions was determined as the number of normal and abnormal prodissoconch I larvae surviving in each test container relative to the seawater control, which was assigned a survival value of 100%. Larvae which failed to transform to the fully shelled, straight hinged, "D" shaped prodissoconch I stage were considered abnormal.

Salinity, dissolved oxygen and pH levels were initially adjusted in each container to 28 ppt, 7.5 mg/L and 8.4, respectively. These parameters were measured in each container at the termination of the bioassay.

Any significant differences in relative survival and percent abnormality between the test and control sediments and the seawater controls were determined by analysis of variance. Specific differences in mean survival and mean percent abnormality were determined by Dunnett's procedure (Miller, 1966) and Duncan's multiple-range test (Steel and Torrie, 1960; Dowdy and Wearden, 1983). One-tailed Dunnett t-tables were used to determine if mean survival and mean percent abnormality in each test series was significantly different from control values. The percent abnormality data were transformed using an ARC SINE transformation ($\sin^{-1}\sqrt{x/100}$ where x = percent abnormal larvae) prior to statistical analysis, as recommended for binomial data expressed as percentages (Steel and Torrie, 1960).

2.5.3 Clam reburial

Various authors (e.g., Rand, 1984; Steele et al., 1985) have noted that behavioral measurements are a sensitive indicator of chemical toxicity, and have recommended their inclusion in bioassay testing. Although such bioassays are still in the early development stages, and there are no "standard" test species or techniques (Rand, 1984), they show great promise. For instance, Akesson and Ehrenstrom (1984) found that the avoidance reactions of dorvilleid polychaetes exposed to chemically contaminated sediments were a much more sensitive indicator of toxicity than was the mortality of the organism.

Burrowing is a critical clam behavior that enables clams to avoid predation; the ecological significance of reduced burrowing is to render the clams more vulnerable to predators (Phelps et al., 1985). Heavy metal levels in sediments have been shown to affect the rate of burial of M. balthica (Eldon and Kristofferson, 1978; Eldon et al., 1980; McGreer, 1979). Mohlenberg and Kiorboe (1983) found that the burrowing behavior of M. balthica was impaired in marine sediments

contaminated with pesticides (6,000 ppm parathion, 200 ppm methyl parathion, 200 ppm malathion) to the extent that in some cases almost no burrowing occurred; there was good agreement between the results of laboratory behavioral experiments and field distributions of this species. However, Phelps et al. (1985), in studies of the burrowing behavior of the clam Protothaca staminea, noted that not all toxic chemicals inhibit burrowing; in some cases, the clams burrowed into sediments contaminated with copper at the same rate as clams in control sediments. However, the clams in the copper contaminated sediments subsequently died.

The infaunal clam Macoma balthica was collected from sediment sieved at low tide from a chemically uncontaminated area of Roberts Bank, B.C. The clams were transported on ice, in clean containers supplied with seawater, and returned to the E.V.S. Consultants laboratory within 18 h of collection.

Following their arrival in the laboratory the clams, which were between 1 and 2 cm in shell diameter, were placed in holding containers filled with clean sediment (from the collection site) and fresh seawater (28 ppt salinity), and maintained under static conditions at 15 ± 1oC until used in testing. Cultures were aerated, but not fed, during acclimation and were held for five days before test initiation. Prior to testing, the clams were hand sorted from the sediments and their taxonomic identification confirmed. Damaged, dead or unhealthy individuals were discarded.

The ability of the clams to rebury in test sediments (i.e., until the clam shells were completely hidden by the sediment) was assessed using circular polyethylene tubs (10 cm diameter x 10 cm deep) filled to a depth of 4 cm with sediment and covered with 350 mL of filtered seawater (28 ppt salinity). A total of 10 clams were placed in each container, on the surface of the sediment, and the time to reburial and any mortalities was assessed. Control sediments from the Macoma collection site were tested concurrently. All tests were run with five replicates at 15 ± 1oC, with aeration under a 14 h light : 10 h dark photoperiod. The number of clams reburied was assessed every 1-5 min for the first hour and then at 1.5, 2, 4, 6, 24 and 48 h. After 48 h the sediments were sieved to remove the clams and any mortalities were determined. Water chemistry (pH, DO, temperature, salinity) values were determined at 0, 24 and 48 h.

The median time for reburial (ET50) was graphically determined for each sample by log-probit methods and any differences in reburial rates were determined by analysis of variance. Lines were fitted to the data plots by eye, following standard procedures for log-probit graphs (Sprague, 1969). Specific differences among the test sediments and the control were determined by Duncan's multiple-range test (Steel and Torrie, 1960; Dowdy and Wearden, 1983).

2.5.4 Harpacticoid copepod bioassay

The harpacticoid copepod Tigriopus californicus is a common intertidal harpacticoid copepod found along the coast of western North America including San Francisco Bay (Burton, 1985). Male copepods

deposit sperm in a receptacle on newly matured females and this single insemination is sufficient to fertilize all eggs produced by the female. Females extrude a single egg sac, which is dropped after 2-3 d, shortly before hatching. Shortly after one egg sac is dropped, another is extruded, and the process continues until death. Females can produce an average of some 300 progeny after one insemination (Burton, 1985).

Harpacticoid copepod bioassays have shown great utility in determining the toxicity of chemicals in water. Antia (1985) tested the effects of the pesticide diflubenzuron on T. californicus and found that reproduction was impaired at levels that had no effect on diatoms. Lassus et al. (1984) determined the relative toxicity of various organic and inorganic chemicals by measuring larval production of T. brevicornis exposed to those chemicals. These authors, using 7-10 d tests and daily measurements of larval production, found that reproductive impairment testing was a good predictor of toxicity.

The harpacticoid copepod reproduction bioassay was adapted for use with sediments by Misitano (1983) and has been used with Puget Sound (Washington State) sediments by Malins et al. (1985). Although this test has not been widely used in sediment toxicity testing, it was incorporated into the present study on the basis that it is presently the only simple reproductive impairment sediment bioassay which can be conducted using ecologically important organisms (harpacticoid copepods are a major prey item consumed by bottomfish and salmonids) that can be cultured in the laboratory and therefore are available on a year-round basis (Burton, 1985; Antia, 1985).

A pure culture of the harpacticoid copepod Tigriopus californicus was obtained from the National Marine Fisheries Service, Mukilteo laboratory and maintained in the E.V.S. Consultants laboratory at 20 $\pm$ 1oC on a 14 h light : 10 h dark photoperiod. The copepods were fed during acclimation and testing on a diet of the alga Isochrysis galbana and held under static conditions without aeration. Seawater (30 ppt salinity) used in all holding and testing was filtered (5 um) and UV-sterilized prior to use. Taxonomic identifications of the test animals were confirmed prior to testing using a Wild M5 dissecting microscope and ovigerous females from a single cohort were removed for the bioassays. Damaged, dead or unhealthy individuals were discarded.

Prior to testing, each sediment sample was sieved through a 64 um screen as recommended by Misitano (1983) and a 1 cm layer of sediment was placed in a clean, acid rinsed (5% HNO_3), 250 mL glass beaker supplied with 150 mL of filtered, sterilized seawater. Nine replicate beakers were run for each station. Eight beakers were used to determine toxicity, while the ninth beaker served as a reference for daily measurement of water chemistry (pH, DO, salinity, temperature). A control seawater treatment was run concurrently. (A control sediment treatment was not tested due to the unavailability of sufficient quantities of clean uncontaminated sediments at particle sizes of less than 64 um). Each beaker was seeded with one newly matured ovigerous female. At weekly intervals, the female was removed and placed in a beaker containing fresh sediment. Egg sacs

that had been released from the female prior to hatching were also transferred to the new test solutions. The remaining contents of the beaker were sieved (64 um) and preserved in buffered formalin/Phloxine B for enumeration of numbers of nauplii produced and relative development to the more advanced copepodite form. The bioassay was continued for 4 weeks, the period during which effects on nauplii production are most likely to be detected (Misitano, 1983). The end points that were measured were survival of the adult female, nauplii production and any abnormalities.

Significant differences in adult survival and in the mean number of nauplii produced among the test sediments and the control during the 4 week exposure period were determined by analysis of variance and Duncan's multiple-range test (Steel and Torrie, 1960; Dowdy and Wearden, 1983).

2.6 Benthic Infaunal Analyses

2.6.1 Sample processing

Benthic infauna samples submitted for complete taxonomic analysis were taken from all three sites (San Pablo Bay, Oakland, and Islais Waterway). Five replicate samples were taken at each of 3 stations within each of these sites. A total of 45 samples were analysed for this study.

Each grab sample was screened alive, in the field, through a 1.0 mm sieve and all macroinvertebrates retained were fixed in 7.0 percent buffered formalin, with Phloxine-B added as a biological tissue stain. After 72 h, each sample was subsequently transferred to 70 percent isopropanol.

Taxonomic analyses involved initially sorting each sample into major constituent taxa (e.g., Amphipoda, Polychaeta, Pelycepoda, Nemertea, Gastropoda, etc.). Ten percent of all sorted samples were randomly resorted as part of routine QA/QC procedures. Sorted samples with greater than 5% of the recorded number of organisms still remaining would have been resorted prior to subsequent taxonomic analysis if necessary, however no such sorting deficiencies were found.

Taxonomic identifications were performed to the lowest possible level consistent with presently available literature. Voucher specimens of all identified taxa were retained in a reference collection preserved in 70% isopropanol, and stored in 4-8 dram lip vials with neoprene stoppers (this method is considered the best for minimizing the loss of fluid over time).

All taxonomic identifications were verified by individuals who have either considerable expertise in a particular group, or who are considered leading taxonomic authorities in such groups as follows:

Amphipoda	- Mr. C. Staude, Friday Harbor, Washington
Polychaeta	- Mr. H. Jones, Corvallis, Oregon
Oligochaeta	- Dr. R.O. Brinkhurst, Department of Fisheries and Oceans, Canada
Mollusca	- Dr. R.G. Reid, University of Victoria, Canada
Cumacea/Ostracoda	- Dr. J. Word, Seattle, Washington
Other Taxa	- Dr. W. Austin, Victoria, Canada

Quality assurance/quality control (QA/QC) procedures used for the benthic infaunal component of this study as discussed above involved random resorting of 10% of all samples, and the maintenance of complete sorting, processing and laboratory records for each sample. All taxonomic identifications were verified by recognized outside experts, and a voucher collection of specimens representing each species (or lowest taxonomic unit of identification) was prepared in a permanent reference collection.

2.6.2 Benthos data analyses

All benthic infaunal data were entered, stored, and analysed on an IBM PC-XT computer. Complex data analyses/manipulations were implemented on an IBM VM/370 mainframe computer through the PC-XT via a modem communications link. Analyses were intended to fulfill two major purposes: 1. to differentiate stations and sites, and 2. to identify adverse impacts (e.g., alteration of communities).

The analyses were based on community descriptive statistics that were calculated for each sample, then summarized for each station (n=5 for each station). Additionally, an overall summary was established for each of the three sites using the data from each of the three stations analysed (n=15). Mean values for each of the parameters described below were derived along with their respective standard error estimates.

The Shannon-Weiner diversity index (H) was calculated for each station using common logarithms. This index, which incorporates both species richness and respective species abundance is calculated as:

$$H = - \sum_{i=1}^{S} P_i \log P_i$$

where S is species richness (the number of species), and Pi is the proportion of species "i" in terms of the abundance of individuals in the entire sample. Pielou's equitability measure (Pielou, 1966), defined as the ratio of diversity (H) to the maximum possible diversity (Hmax = log(s)), was similarly calculated. A dominance measure, equivalent to the complement of equitability, was also calculated and summarized as outlined above.

The numerical contributions of major taxonomic groups (i.e., Polychaeta, Mollusca, Amphipoda, and others) was calculated as a proportion of the taxon abundance to total abundance for each of the 45 samples. This analysis included and emphasized ecologically

sensitive taxa. Mean proportions, expressed as percentages, were also determined (with their standard errors) for stations (n=5) and for each of the study sites (n=15).

Numerical dominance, calculated as the complement of equitability (1-J) was related to the proportions of these major taxonomic groups. Through examination of the "raw" data, one or two specific taxa were subsequently identified as contributing significantly to observed increases in this parameter.

Between-station and between-site species abundances were compared using a hierarchical, or cluster analysis. Each matrix of mean species abundances, i.e., per station (n=5) and per site (n=15), was analysed to allow comparison of samples based on the similarity of species abundances and on their respective abundances. The complement of the Bray-Curtis coefficient was employed as the index of similarity in both cases. This index is defined as follows:

$$C = 1 - (2w\ (a+b))$$

where w is the sum of the lesser abundances for each species common to a pair of samples and (a+b) is the sum of the abundances for each sample under comparison.

An unweighted pair-group clustering algorithm was applied to each of the resulting similarity matrices. Results were displayed as an optimally rotated dendrogram (i.e., clusters were rotated and displayed such that most similar groups were located together), with each similarity matrix included for reference to specific between-station (or site) similarities.

Species richness, total abundance, numerical dominance, and relative major taxon proportions were all further expressed in terms of the Ratio-to-Reference (RTR). For this study, the means of each parameter from the San Pablo Bay (SP) site (n=15) were used as the reference values. Mean RTR values for each of the other stations (n=5) and sites (n=15) were divided by mean San Pablo Bay site values to yield RTR values that were either greater than 1.0 (greater than reference), equal to 1.0 (equal to reference) or less than 1.0 (less than reference).

Species abundances were further analysed using the log-normal "fit" of the distribution of individuals amongst species. This method, described by Gray and Mirza (1979) has been particularly useful in the detection of pollution-induced disturbances in many benthic communities. Given that a large sample is drawn from a heterogeneous population, the distribution of individuals among species usually follows a log-normal relationship under "normal" environmental conditions. Changes in environmental conditions (e.g., through effects of anthropogenic pollution) can be identified in this analysis through deviations from the log-normal curve. In this study the requirement of a large sample size for log-normal analysis was satisfied by pooling data from all 15 samples within each of the study sites. Because the number of species (represented as a cumulative percentage of the total sample richness over each geometric class) is linearly related to the geo-

metric classes of individuals per species if the distribution of individuals among species is indeed log-normal, a simple graphical presentation of these data will reveal an apparent "fit" or lack of "fit" to the log-normal distribution.

3.0 RESULTS

3.1 Sediment Characterization

Detailed results of the physical and chemical analyses performed on the nine sediment samples, three from each site, are presented in Appendix B, together with QA/QC data. Summary data for the major groups of substances measured are presented below. Detailed statistical analyses of these data were inappropriate due to the lack of replication of these measurements per station, and were not undertaken.

3.1.1 Conventional parameters

It had been hoped when the sites were selected that the sediments from all nine stations would be similar in texture and in their organic content. The data from the nine stations analysed are presented in Figure 3 as a bar chart of the percentages of sand, silt and clay and the percentage of TOC in the sediments (note that the percentages of TOC have been multiplied by 10 in order to more clearly illustrate the spatial differences among the stations). The stations from the San Pablo Bay and Oakland sites showed the same relative textural composition, being dominated by the clay fraction. The one exception was SP02, which was the only station analysed in which the sand component dominated the sediments. The stations toward the head of Islais Waterway had very high levels of silt, constituting over 80% of sediment dry mass in comparison to less than 20% silt in the sediments from other sites. The silt content decreased toward the mouth of the waterway and at Station IS09 the texture was similar to that of the sediments from the San Pablo Bay and Oakland sites.

The levels of organic matter in the sediments showed trends similar to those of texture. Total organic carbon (TOC) was very highly correlated with total volatile solids (TVS) and therefore this discussion will consider only the former measurement. At San Pablo Bay, Oakland and at the outer Islais Waterway station (IS09), the percentages of TOC in the sediments were similar and in the normal range for estuarine sediments, 1% to 2% of the dry weight (note scale multiplier applied for visual clarity in Fig. 3). The TOC content increased dramatically, however, at the two inner Islais Waterway stations (IS02 and IS05).

The TOC content of the sediments increased in proportion to the amount of fine-grained sediment in the samples. This relationship was not unexpected because it is known that organic matter will accumulate on finer sediments, and some organic matter is fine-grained. The linear relationship between TOC and sediment texture was strongest for the silt fraction (Fig. 4a). A similar linear relationship was observed between TOC and the percentages of clay

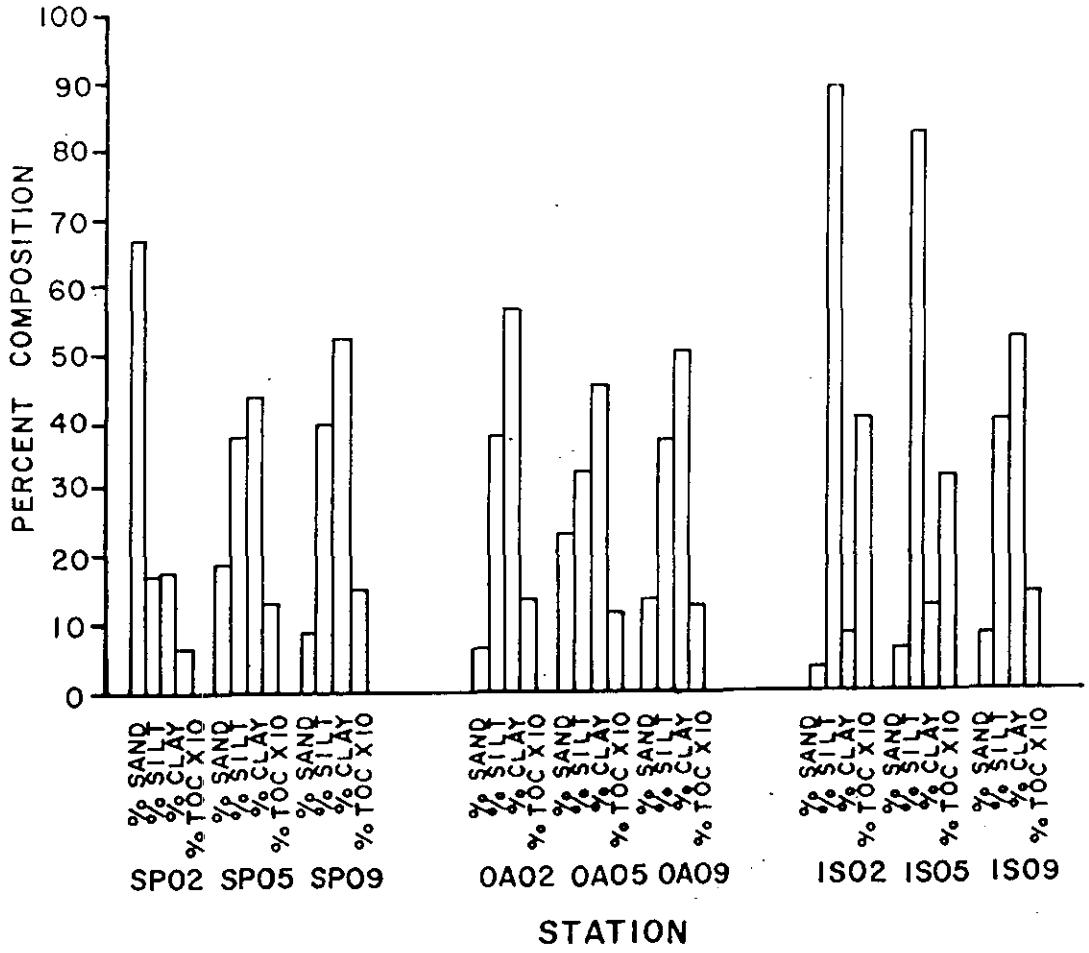


Figure 3. Sediment texture and organic matter. Percent composition is shown on a dry mass basis.

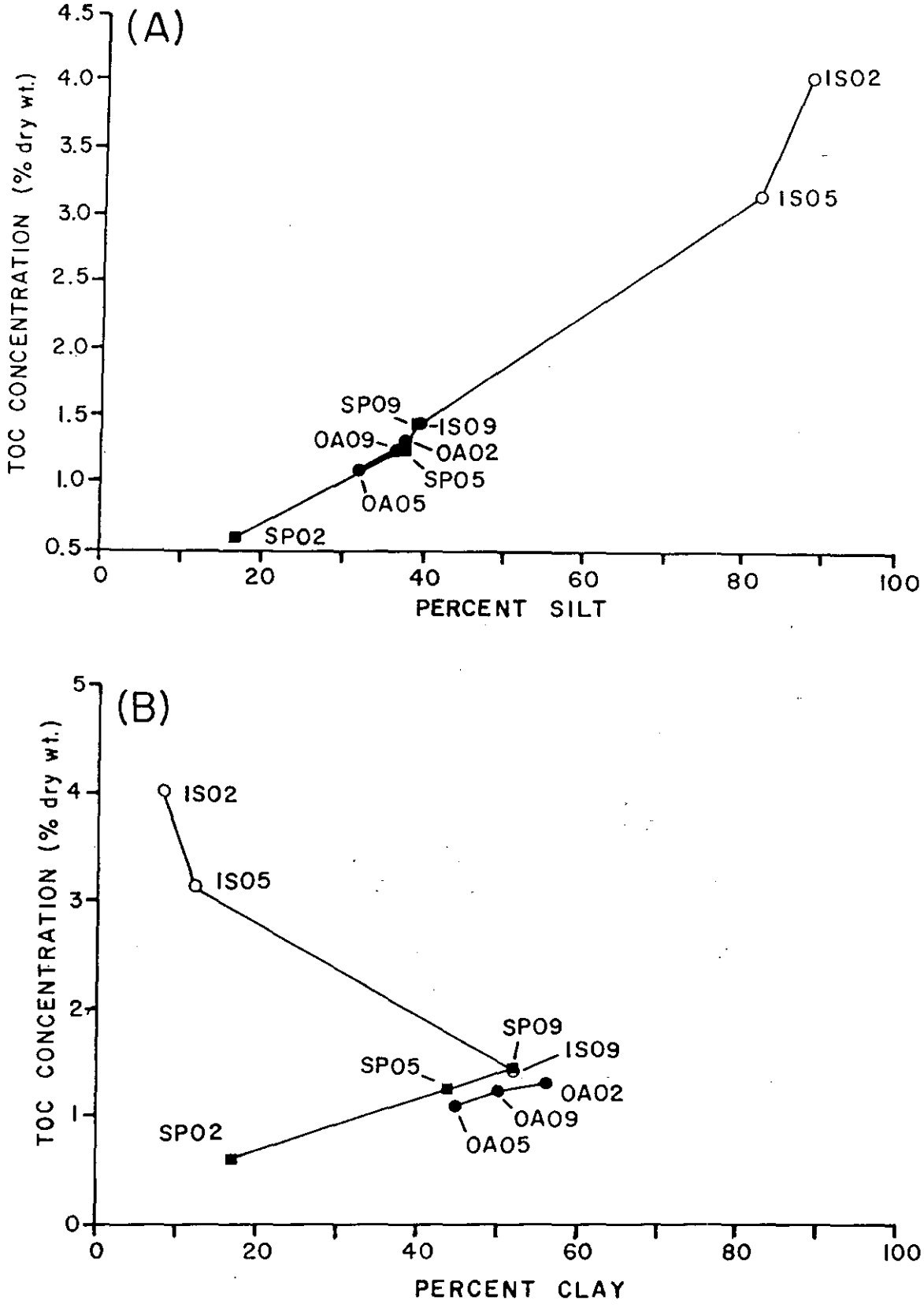


Figure 4. Plot of Total Organic Carbon (TOC) versus (a) percent silt and (b) percent clay. The solid lines in this and in subsequent similar plots have been included to identify stations from the same sites. These lines are not intended to imply scale continuity between connected symbols

(Fig. 4b), with the major exceptions that the very high TOC levels near the head of Islais Waterway were in sediments that had a low clay content.

Consistently elevated concentrations of sulfides (cf. Appendix B) were found only in the high TOC sediments of Islais Waterway. All stations in the waterway had detectable levels of sulfide and the concentrations decreased in a gradient from the head of the waterway toward the mouth. This gradient followed the decreasing TOC content of the sediments at those stations.

3.1.2 Major elements

A detailed listing of the concentrations of the major elements measured at each station (aluminum, Al; silicon, Si; iron, Fe; manganese, Mn; magnesium, Mg; calcium, Ca; sodium, Na; and titanium, Ti) is presented in Appendix B (Table B.2), and the data are summarized as a bar chart in Figure 5. The data in Figure 5 are the ratios between the individual station concentrations for each element and the mean concentration of that element observed at the San Pablo Bay site. The latter site was considered to be the least chemically contaminated (R. Spies, Lawrence Livermore National Laboratory, pers. comm.) and hence the most likely to represent "background" conditions in the Bay. This general area has been used as a reference area by R. Spies in his studies of starry flounder. While it is not pristine, Spies has shown it to be much less contaminated than his other study sites near Berkeley and Oakland (R. Spies, pers. comm.; Spies et al., 1985). It was thus used as the reference site for this study. The chemical concentrations were normalized to the reference site data to facilitate the display of spatial differences among the stations and to allow presentation of the data for chemical parameters with widely different concentration ranges on the same graphic scale for each chemical group.

Very few differences in the concentrations of the major elements were observed among the stations. The exceptions include some indication of decreased levels of manganese (Mn) and calcium (Ca) in the Islais Waterway sediments. Loss of manganese could be related to the reduction and mobilization of this element in the anoxic sediments of that site. No explanation for the decrease in calcium was apparent.

3.1.3 Trace elements

A detailed listing of the concentrations of the trace elements observed in the sediments at each station is presented in Appendix B (Table B.3). Of the 12 trace elements analysed, antimony (Sb), beryllium (Be), and thallium (Th) were never present above the detection limits of the procedures used. Cadmium (Cd) was detected only once, at a level of 1 mg/kg, at Station IS02 at the head of Islais Waterway. The remaining elements (arsenic, As; chromium, Cr; copper, Cu; nickel, Ni; zinc, Zn; lead, Pb; mercury, Hg; tin, Sn; and silver, Ag) were always detected and data for these elements are summarized in Figure 6 as a bar chart of their concentrations relative to the mean concentrations observed at San Pablo Bay.

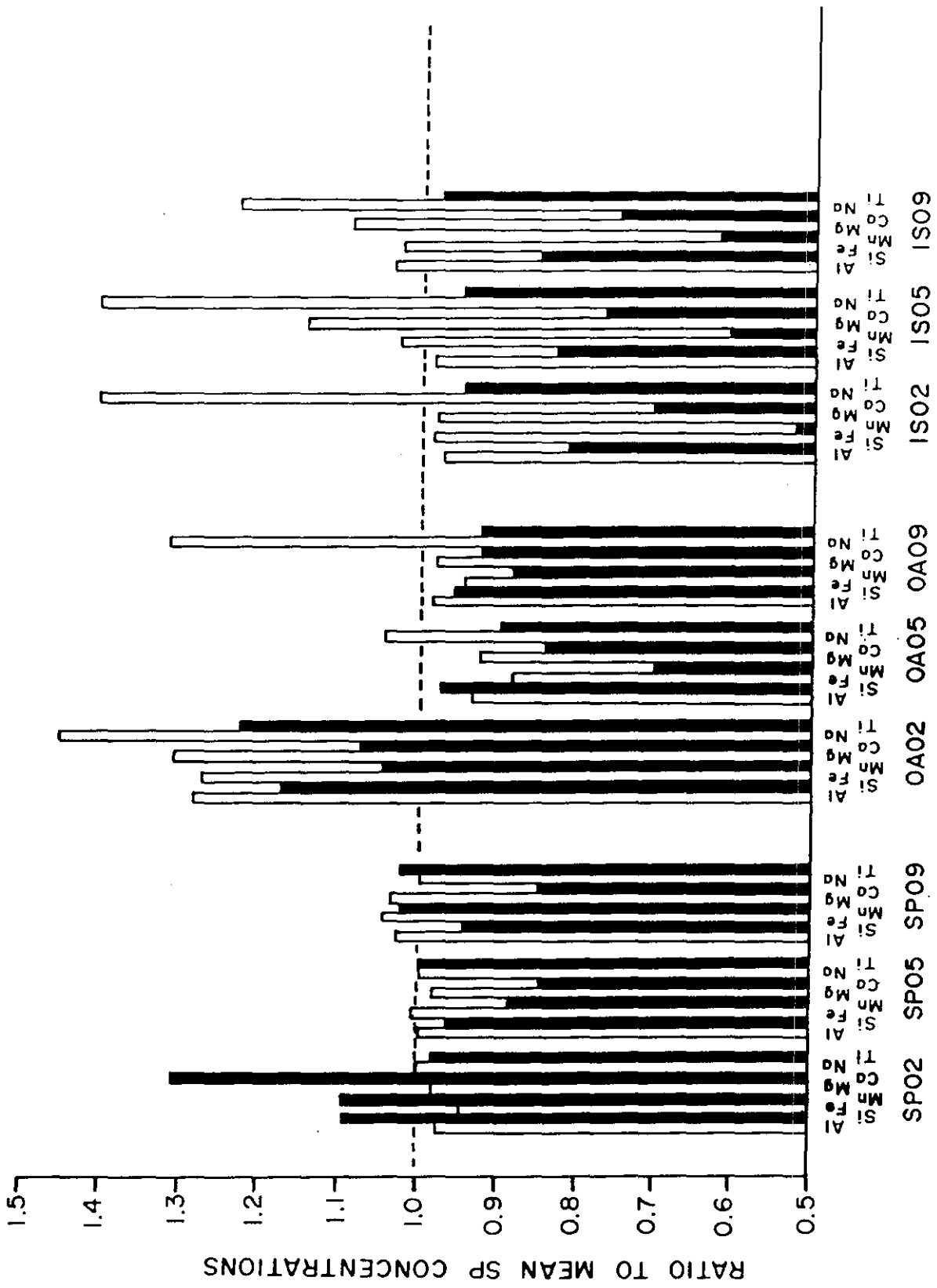


Figure 5. Ratios between mean reference site (SP) values and individual station values for major elements.

As was the case with the major elements, only a few of the trace elements showed substantial differences in concentration among any stations. In Islais Waterway, the levels of lead (Pb), mercury (Hg) and silver (Ag) were all much greater than observed at any station at the other two sites. The concentrations of lead were highest near the head of the waterway and appeared to decrease toward the mouth. The levels of mercury and silver both were greatest at IS05 but also decreased considerably toward the mouth of the waterway. Copper (Cu), tin (Sn) and zinc (Zn) were also elevated in Islais Waterway, but to a much lower extent. No other trace elements were present at levels that exceeded even twice the reference site levels, although the concentrations at the Oakland stations were slightly greater than observed at San Pablo Bay, particularly for silver.

The possible relationship between the concentrations of the trace metals and the TOC phase of the sediments was investigated. Simple scatter plots of the levels of lead and of silver as functions of TOC (Figs. 7 and 8) clearly showed the strong linear relationship between the TOC levels and the concentrations of these metals. These relationships were apparent in the similarities of the bar charts for these parameters (Figs. 3 and 6) and were expected because the ability of fine-grained and high TOC sediments to accumulate trace metals is well recognized (DeGroot et al., 1976; Dexter et al., 1981; Quinlan et al., 1985).

Replotting the trace element data on a bar chart, but using the TOC-normalized data (i.e., the dry mass trace element concentrations divided by the dry mass TOC concentrations) (Fig. 9), illustrated the reduction in the differences among the sites that occurred when the TOC content of sediments was taken into account. The data still clearly indicated, however, that Islais Waterway was contaminated with lead, mercury and silver.

3.1.4 Organic chemicals

Analyses were performed for 36 organic compounds covering a wide spectrum of possible chemical types. For simplicity of presentation and to maintain real associations among different chemicals, the organic compounds were subdivided into the following three groups: the low molecular weight polynuclear aromatic hydrocarbons (LPAH), consisting of 2- to 3-ring aromatic hydrocarbons and some of their methylated derivatives; the high molecular weight polynuclear aromatic hydrocarbons (HPAH), consisting of 4- and greater-ringed aromatic compounds; and the chlorinated hydrocarbons, including chlorinated hydrocarbon pesticides and the polychlorinated biphenyls (PCBs). A few miscellaneous hydrocarbons, biphenyl, perylene and coprostanol (an indicator of fecal contamination) have been included with the HPAH.

Low Molecular Weight Aromatic Hydrocarbons (LPAH) - A detailed listing of the concentrations of the LPAH observed at each station is presented in Appendix B (Table B.4), and the data are summarized in Figure 10, a bar chart of the concentrations relative to the average levels observed at the San Pablo Bay site. It is clear

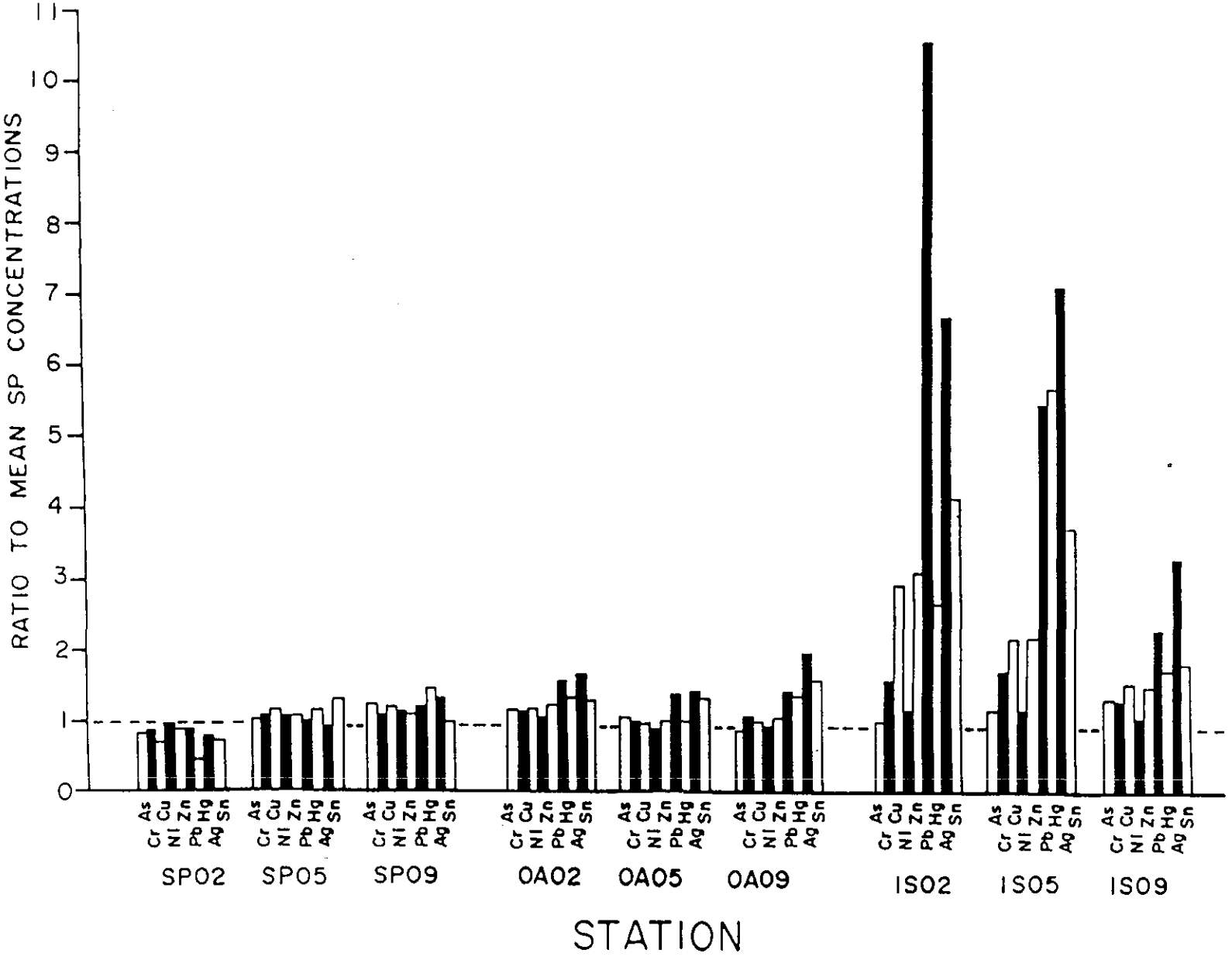


Figure 6. Ratios between mean reference site (SP) values and individual station values for trace elements. Antimony, beryllium and thallium were always below detection limits; cadmium was only detected at Station IS02 (thus these compounds are not shown here).

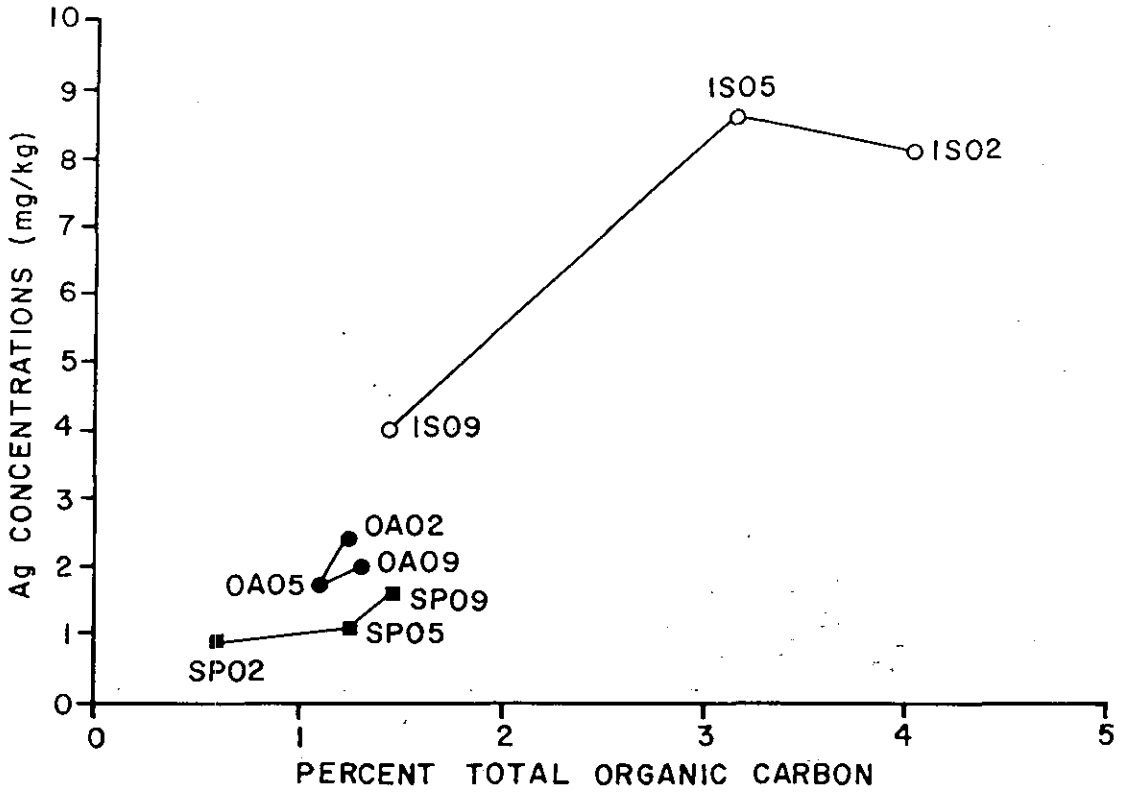


Figure 7. Scatter plot of silver concentration versus percent TOC.

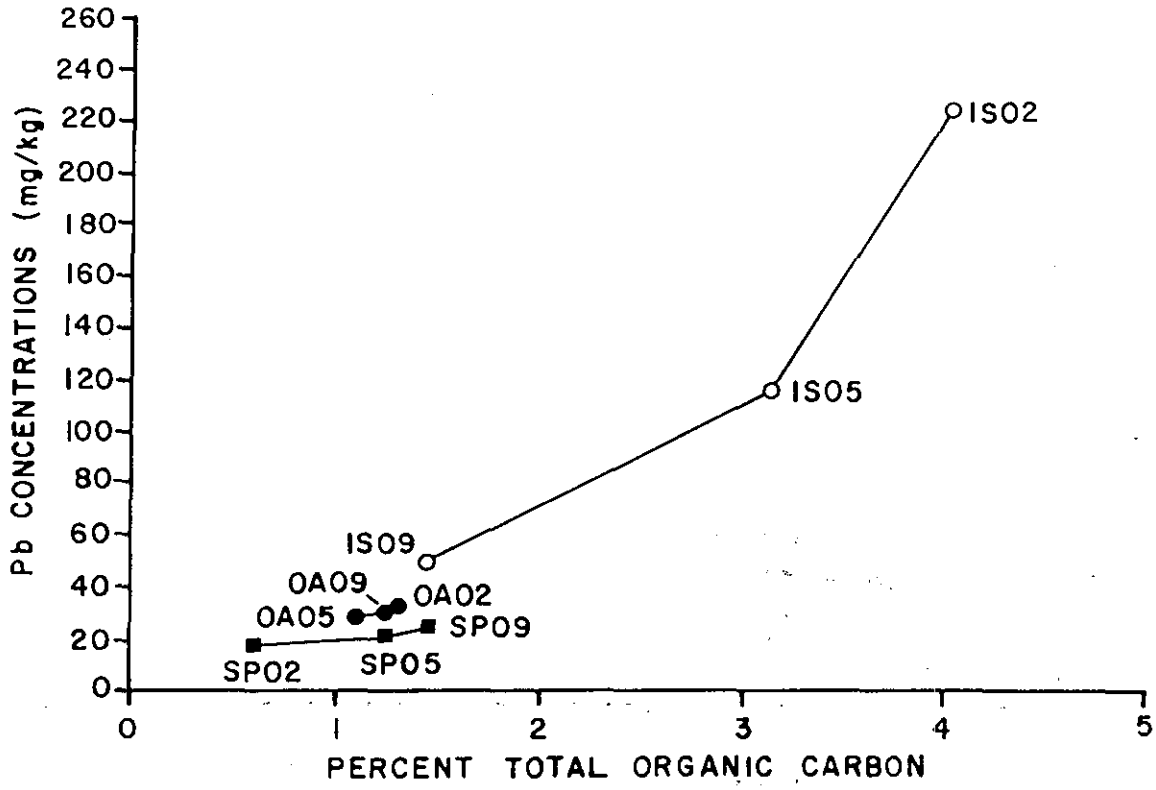


Figure 8. Scatter plot of lead concentration versus percent TOC.

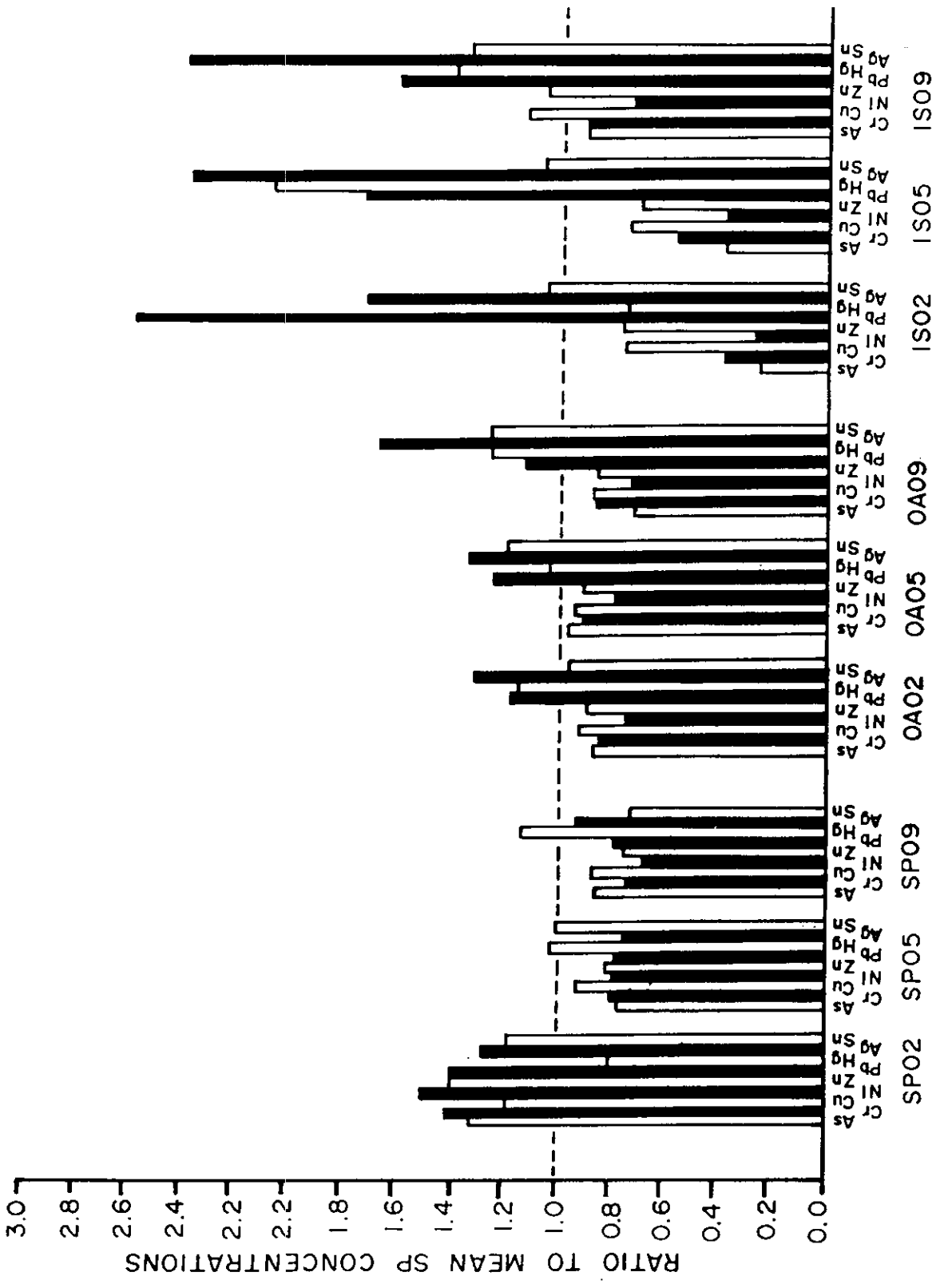


Figure 9. Ratios between mean reference site (SP) values and individual station values for TOC-normalized data for selected trace elements.

that Islais Waterway was substantially contaminated with LPAH, while Oakland had slightly greater concentrations than those observed at San Pablo Bay. The general trend was very similar to that of lead, with an apparently decreasing gradient in the concentrations of the LPAH, from the head of the waterway (IS02) toward the mouth (IS09). In the case of the LPAH, however, the extent of the contamination was much greater. In addition to the overall enrichment in Islais Waterway, there were also some differences in the relative concentrations within the LPAH group. For example, at both San Pablo Bay and Oakland, phenanthrene was present at about three times the concentration of anthracene, while in Islais Waterway, anthracene exceeded phenanthrene by a factor of two.

A scatter plot of the relationship between the concentrations of the LPAH and TOC (Fig. 11) demonstrated that this group of compounds was also highly associated with the TOC-rich sediment fraction. Replotting the bar chart using the TOC-normalized LPAH values (Fig. 12) diminished the overall difference among the sites, but still identified Islais Waterway as a contaminated site and also more clearly showed the slightly higher concentrations observed at Oakland compared to San Pablo Bay.

High Molecular Weight Aromatic Hydrocarbons (HPAH) - A detailed listing of the concentrations of the HPAH observed at each of the stations is presented in Appendix B (Table B.5), and the data are presented in Figure 13 as a bar chart of the concentrations relative to the average concentrations observed at the San Pablo Bay site. As with the previously discussed substances, the concentrations of HPAH were substantially greater near the head of Islais Waterway compared to the other sites, and appeared to decrease toward the mouth of the waterway. The sediments from the Oakland site were slightly elevated in HPAH compared to the San Pablo Bay site. Some slight compositional differences were noted in the HPAH compounds in Islais Waterway, with chrysene, benzo(a)anthracene and fluoranthene being particularly enriched in the sediments from this waterway.

The HPAH were also strongly associated with the TOC phase of the sediments (Fig. 14) and plotting of the TOC-normalized data substantially reduced, but did not eliminate the differences in concentration among sites (Fig. 15).

Of the other compounds considered under this heading, coprostanol, a compound produced in the intestines of mammals and thus a good indicator of fecal contamination (Romberg et al., 1984), was present at very high concentrations in the sediments of Islais Waterway. The levels in Islais Waterway were more than 60 times greater than the levels observed at San Pablo Bay, and decreased from the head of the waterway toward the mouth. The concentrations of coprostanol at the Oakland site were roughly twice those found at the San Pablo Bay site.

Biphenyl appeared to be highly correlated with the LPAH, while perylene showed only modest differences among the sites (maximum enrichment in Islais Waterway was a factor of 3 greater than the mean San Pablo Bay reference value).

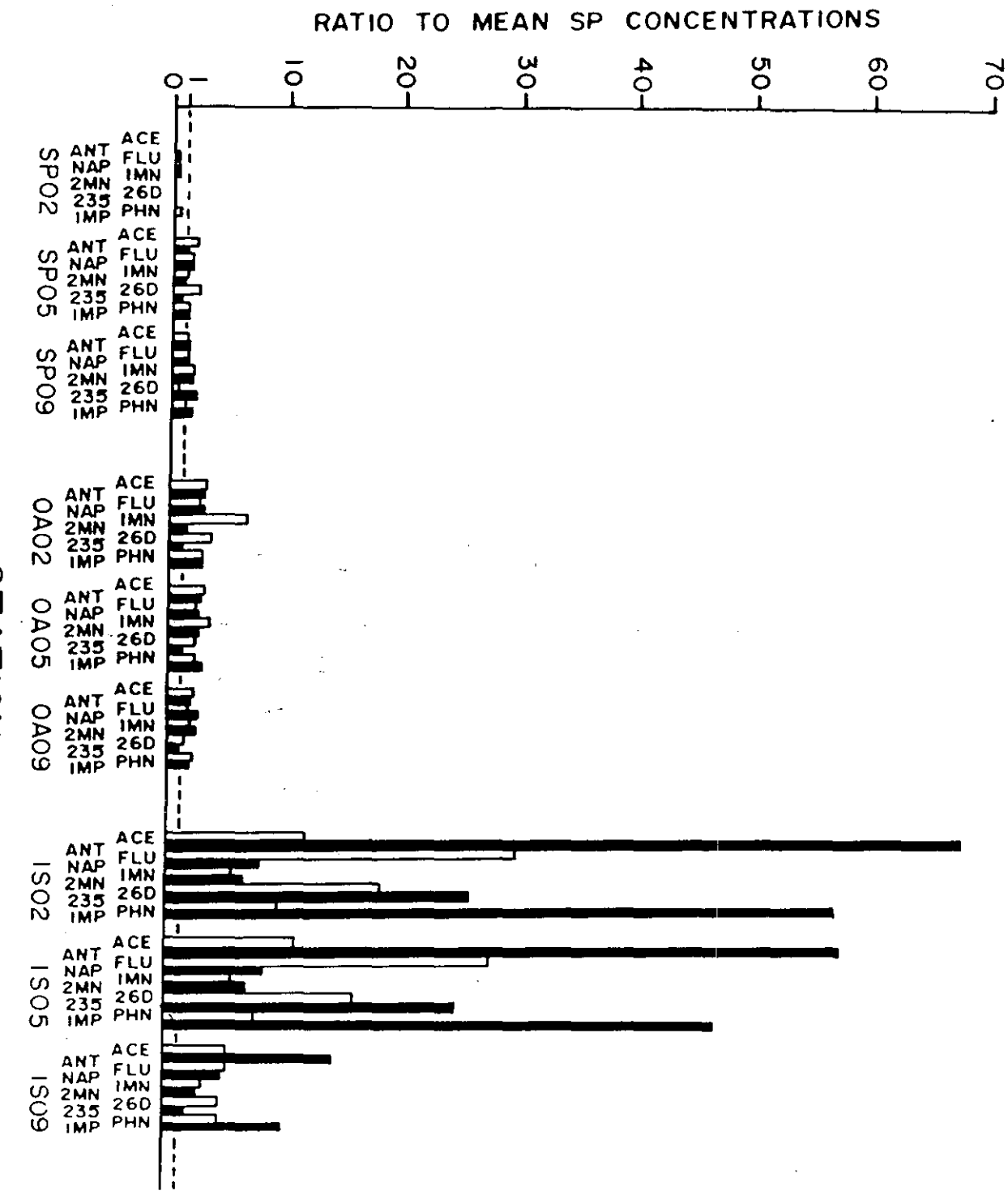


Figure 10. Ratios between mean reference site (SP) values and individual station values for LPAH compounds. Abbreviations are explained in Table 1.

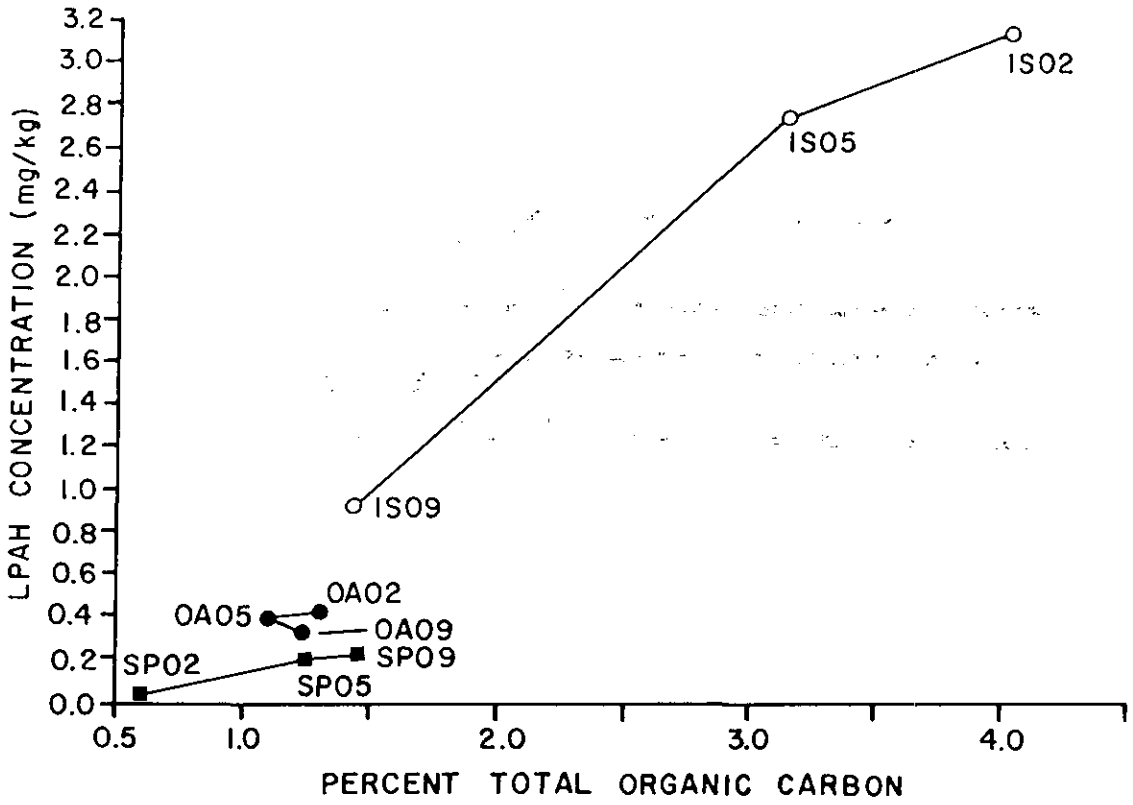


Figure 11. Scatter plot of LPAH concentrations versus percent TOC.

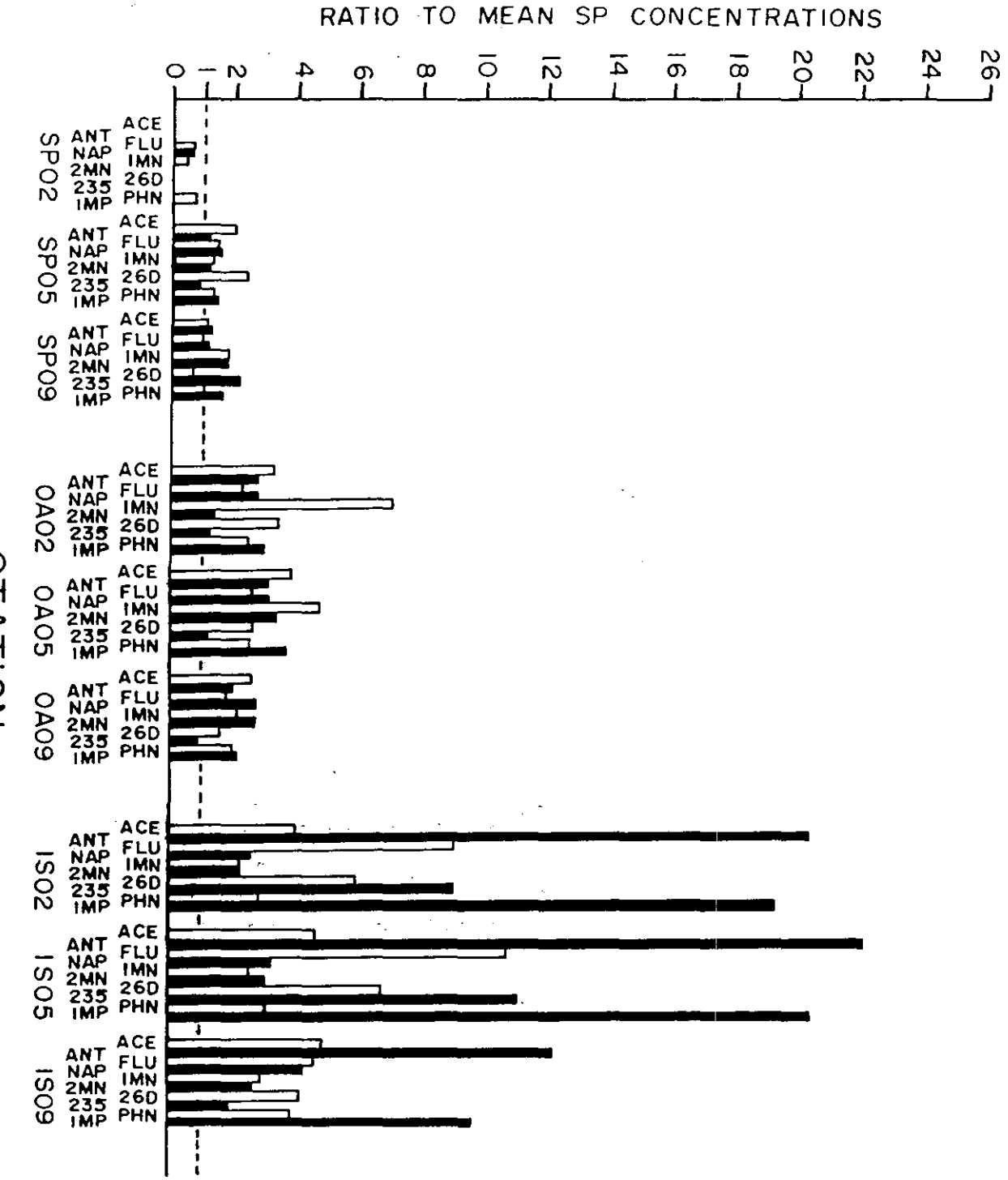


Figure 12. Ratios between mean reference site (SP) values and individual station values for TOC-normalized data for the LPAH. Abbreviations are explained in Table 1.

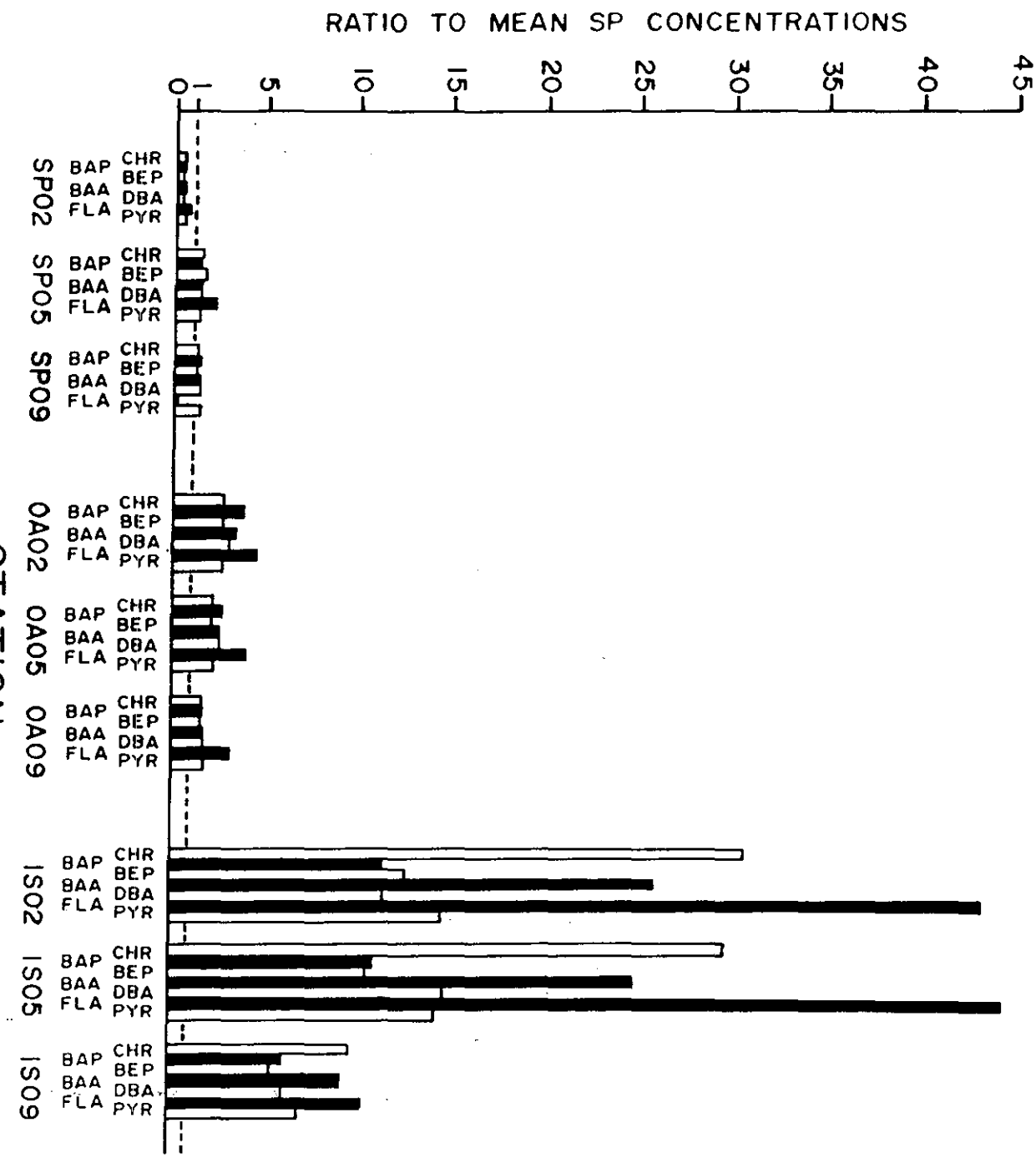


Figure 13. Ratios between mean reference site (SP) values and individual station values for HPAH compounds. Abbreviations are explained in Table 1.

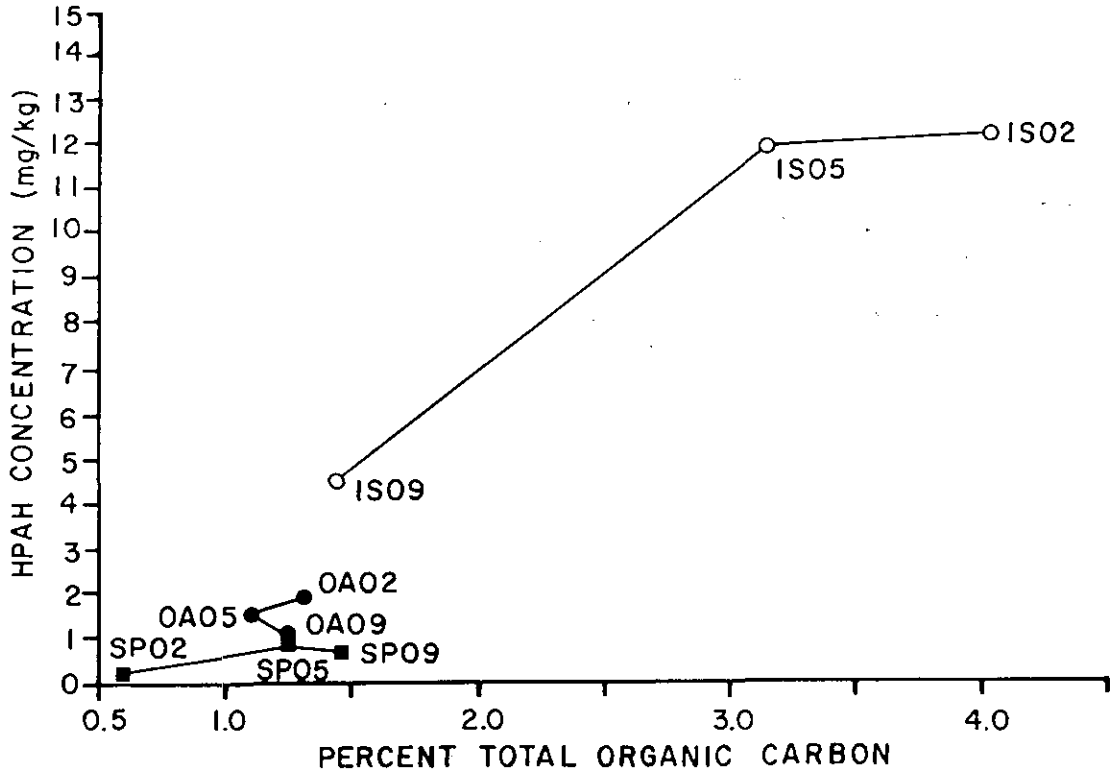


Figure 14. Scatter plot of HPAH concentrations versus percent TOC.

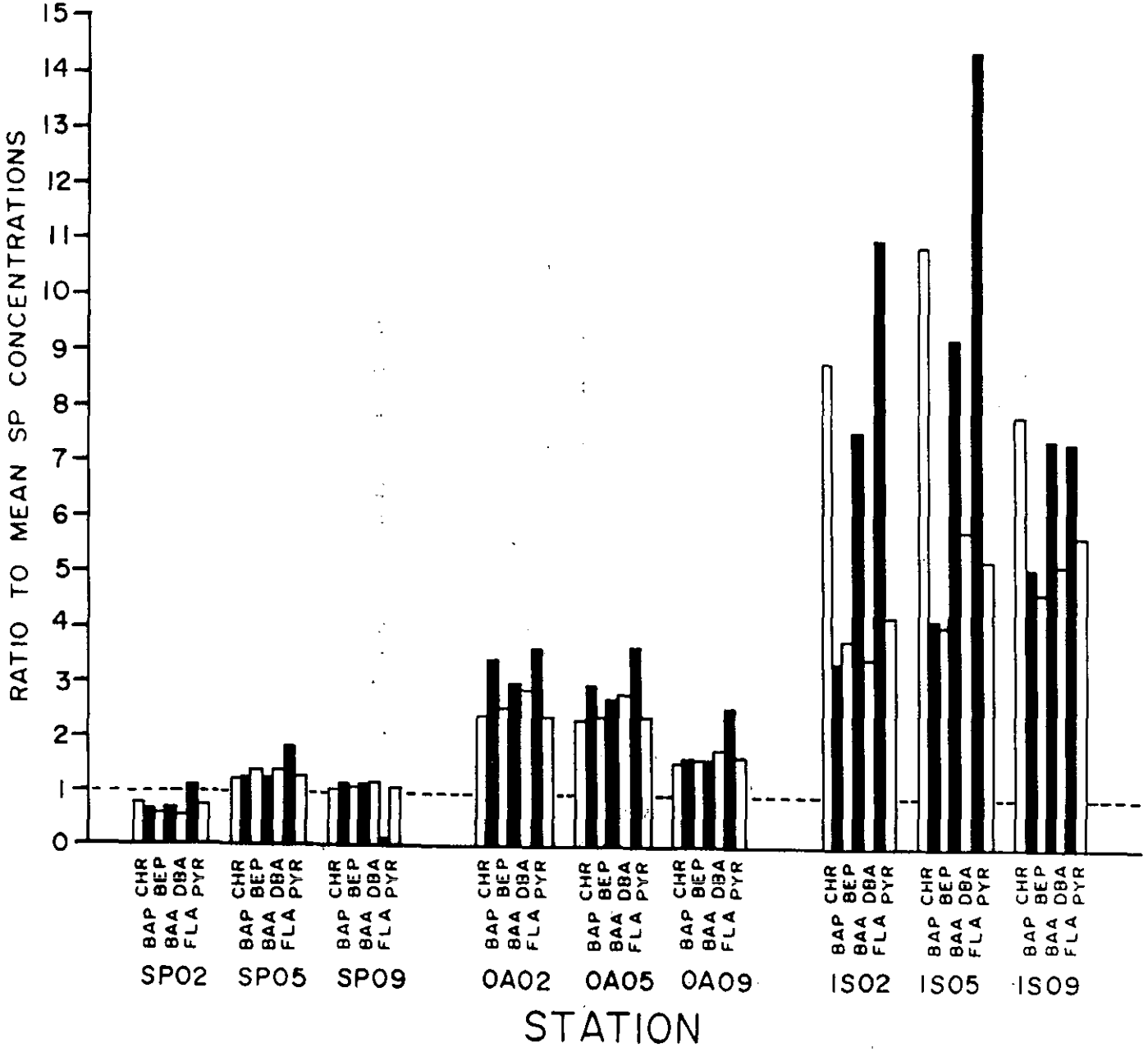


Figure 15. Ratios between mean reference site (SP) values and individual station values for TOC-normalized data for the HPAH. Abbreviations are explained in Table 1.

Because eucalyptus (Eucalyptus sp.) leaves were seen quite frequently during the sediment sampling of Islais Waterway, an attempt was made to find detectable quantities of potentially toxic chemicals that could have derived from the leaves. Examination of the mass spectra obtained from the analyses did not reveal the presence of any eucalyptus-derived chemicals. However, the most prevalent components, e.g., eucalyptol and related compounds, are quite volatile compared to most of the substances of interest to this study, and hence, the former compounds may have been lost during sample extraction and preparation. The toxicity of these compounds in the aquatic environment is unknown.

Chlorinated Hydrocarbons - Of the 17 chlorinated compounds analysed, only six chlorinated pesticides and the PCBs were detected in at least one sample. A detailed listing of the concentrations of these detected compounds is presented in Appendix B (Table B.6). Of the compounds detected, trans- and cis-chlordane and trans-nonachlor were only detected at the two inner stations in Islais Waterway (IS02 and IS05). Only pp'-DDT, its metabolites pp'-DDE and pp'-DDD and the PCBs were routinely detected at most stations. The composition of the PCBs present was similar at most of the stations and consisted of approximately 30% dichlorobiphenyls, 20% trichlorobiphenyls, 15% tetrachlorobiphenyls, 15% pentachlorobiphenyls, and 20% hexachlorobiphenyls. However, the two stations at the head of Islais Waterway differed from the others. At IS02, the PCBs consisted of 18% dichlorobiphenyls, 9% trichlorobiphenyls, 43% tetrachlorobiphenyls, 11% pentachlorobiphenyls, and 19% hexachlorobiphenyls, while at IS05 the PCBs consisted of dichlorobiphenyls, tetrachlorobiphenyls, and pentachlorobiphenyls at similar levels to those observed at the San Pablo Bay and Oakland stations, but with lower relative levels of trichlorobiphenyls (13%) and higher levels of hexachlorobiphenyls (27%). No chlorobiphenyls with more than six chlorines were observed at any station.

Figure 16 presents a bar chart of the data for the PCBs and DDTs as their concentrations relative to the concentrations observed at the San Pablo Bay site. The spatial trends in the concentrations of the DDTs and PCBs were similar to those observed for the other compounds. However, the magnitude of the difference between San Pablo Bay and Islais Waterway was smaller for both the DDTs and for the PCBs than was seen for the PAH compounds. Both of these chemical types were linearly related to the TOC content of the sediments (Figs. 17 and 18), and normalization of the values to the TOC content of the sediments substantially reduced, but did not eliminate, the spatial differences (Fig. 19).

3.1.5 Summary

Because the chemical substances that were measured in the sediments of San Francisco Bay were primarily those that are subject to anthropogenic enrichment, it was not surprising that compounds from all of the chemical groups were substantially elevated in the site expected to be most chemically contaminated, Islais Waterway. The Islais Waterway site showed the highest level of contamination of the

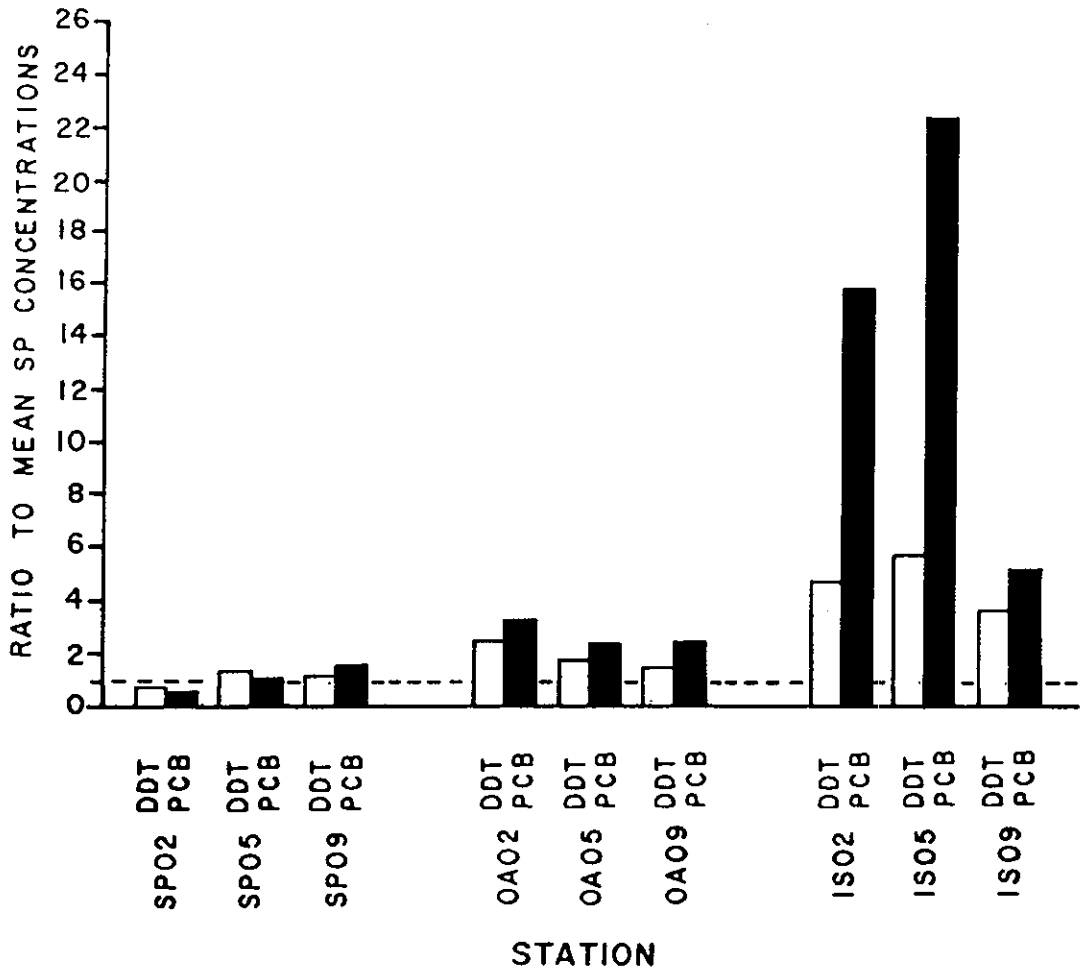


Figure 16. Ratios between mean reference site (SP) values and individual station values for DDTs and PCBs.

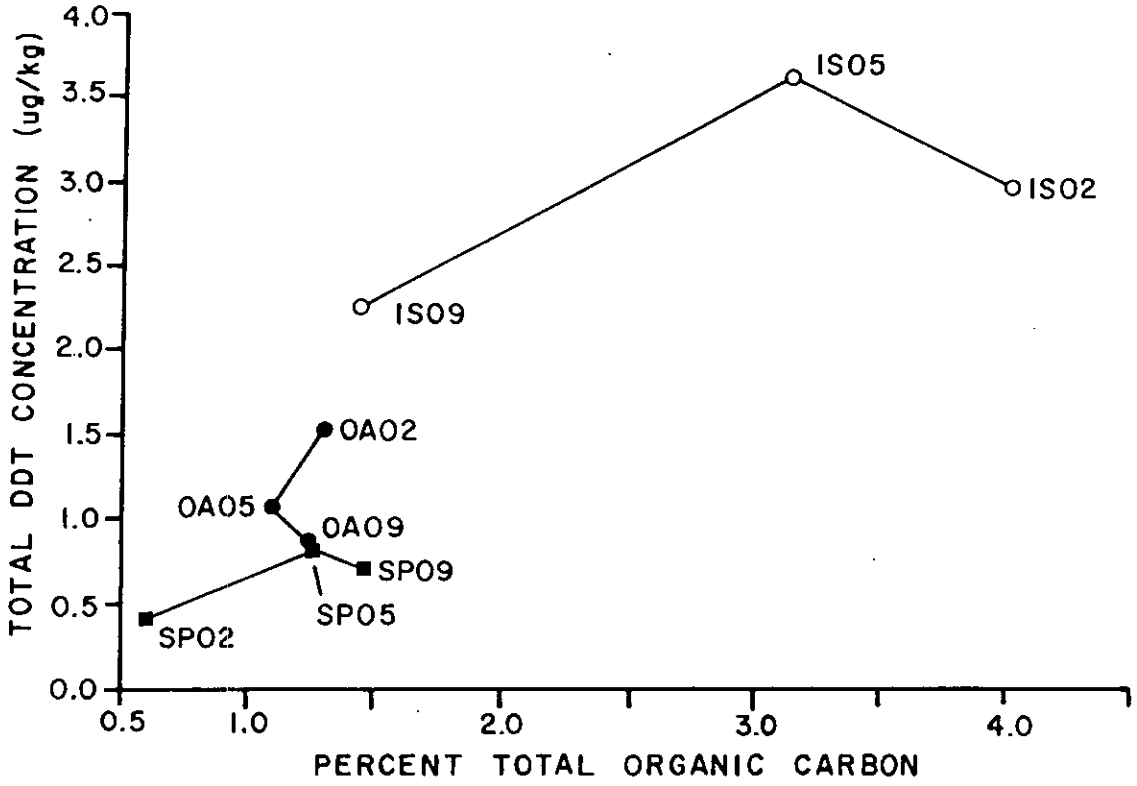


Figure 17. Scatter plot of DDT concentrations versus percent TOC.

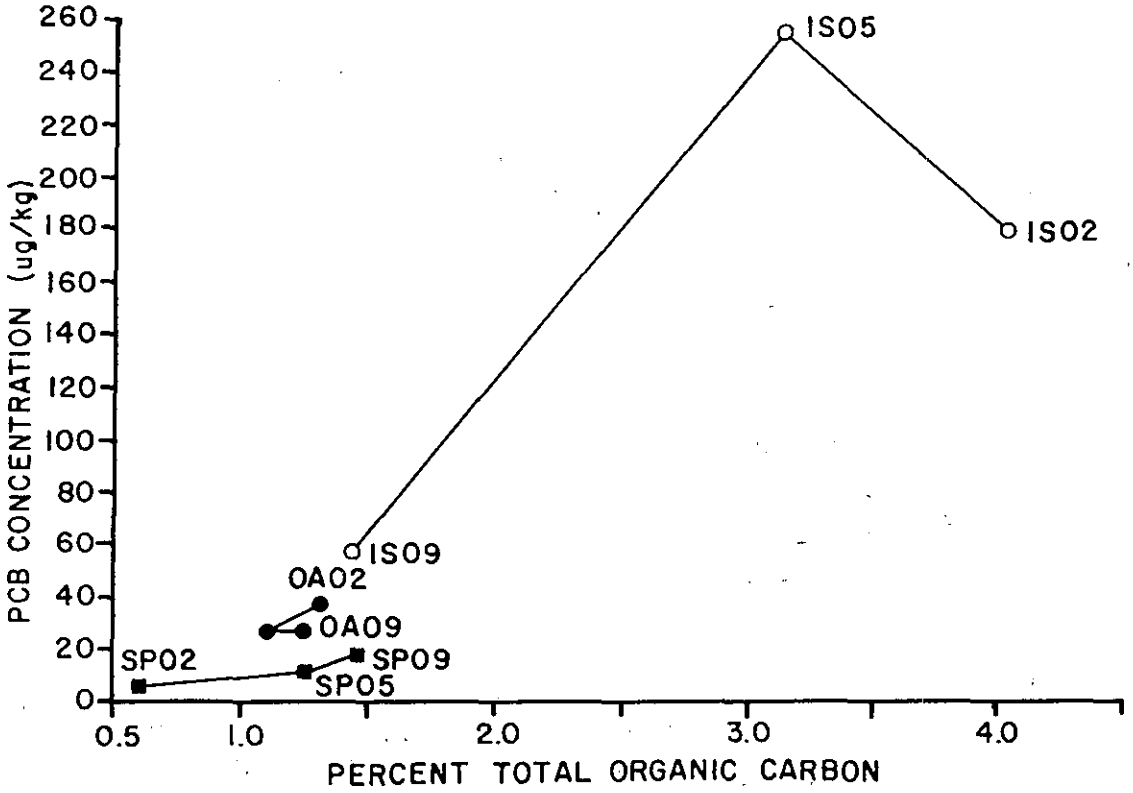


Figure 18. Scatter plot of PCB concentrations versus percent TOC.

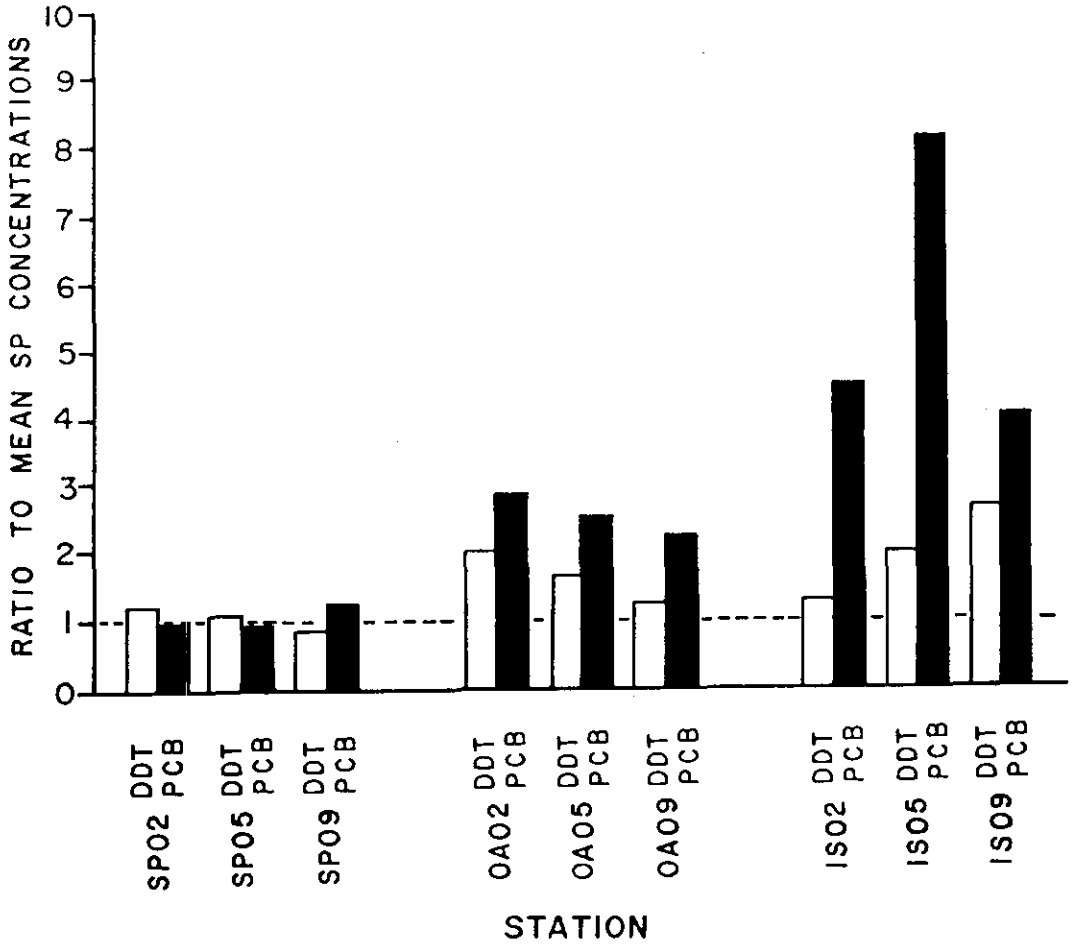


Figure 19. Ratios between mean reference site (SP) values and individual station values for TOC-normalized data for DDTs and PCBs.

three sites studied. The data from Islais Waterway were consistent in establishing a gradient of contamination from the head of the waterway (west of the 3rd Street Bridge) toward the mouth.

The Oakland site was enriched by the same substances that were present in elevated concentrations in Islais Waterway when the Oakland values were compared to those from the San Pablo Bay site. However, these elevations were small compared to the levels observed in Islais Waterway and many disappeared upon normalization to TOC. As had been expected, the San Pablo site had the lowest concentrations of all of the substances measured during this study.

3.2 Toxicity Testing

3.2.1 Amphipod bioassay

Results of the amphipod bioassays are summarized in Table 2. Detailed results, including raw data, are provided in Appendix C.

Mean survival in the test sediments ranged from a low of 0 (IS04) to a high of 19.2 (SP05) out of 20. Mean survival in the sediment control collected from Washington State was 18.8 (94%). Results of the analysis of variance indicated that significant differences in survival occurred ($F=20.5$, $P=0.005$). Survival in the sediments from the Islais Waterway site, and for 8 out of 10 Islais Waterway stations sampled, was significantly lower ($P=0.05$) than the control. In contrast, only one station out of 20 between the San Pablo Bay and Oakland sites had a mean survival significantly lower ($P=0.05$) than the control.

Mean avoidance in the test sediments ranged from a high of 9.1 (IS01) to a low of 0.2 (IS10) out of 20. Mean avoidance in the sediment control was 1.3. Results of the analysis of variance indicated that significant differences in avoidance occurred ($F=13.6$, $P=0.005$). Significantly higher avoidance than the control ($P=0.05$) was determined for four Islais Waterway stations (IS01, 02, 03 and 04).

Water quality parameters during testing (Appendix C) ranged from: temperature, 14.5-16.5°C; salinity, 27-30 ppt (except for SP04 which dropped to 24 ppt from Days 6 to 10); pH, 7.9-8.4; DO, greater than 5.0 mg/L. Interstitial salinity values at test initiation ranged from 25 to 36 ppt and were lowest at the head of Islais Waterway.

Oxidation/reduction potentials (Eh) of the sediments obtained just prior to amphipod exposure (Day 0) were -60 to -170 mV for San Pablo Bay samples, -80 to -190 mV for Oakland samples, -170 to -340 mV for Islais Waterway samples and -70 to -160 mV for the controls. These values were taken at the top (0 cm), middle (1 cm) and bottom (2 cm) of the test sediments in the bioassay jars. Variation in these values from top to bottom was generally less than 50 mV with larger negative values obtained at the bottom of the sample jars. Surface Eh values obtained at the end of testing (Day 10) were all higher than the Day 0 values indicating that oxidation of the surface sediments had occurred. These latter values ranged from +40 to +80 mV for the

Table 2. Summary of amphipod bioassay results

Station	Mean Values ± S.D.[a] Survival[b]	Avoidance[c]
SP01	17.6 ± 2.3	0.5 ± 0.3
SP02	18.2 ± 1.6	1.1 ± 0.9
SP03	17.4 ± 1.5	0.8 ± 0.3
SP04	16.0 ± 4.4	0.8 ± 0.6
SP05	19.2 ± 0.8	0.5 ± 0.7
SP06	18.4 ± 1.3	0.4 ± 0.4
SP07	16.8 ± 0.4	0.4 ± 0.3
SP08	14.2 ± 7.0*	0.3 ± 0.2
SP09	15.2 ± 2.2	0.5 ± 0.3
SP10	17.8 ± 1.8	0.4 ± 0.2
SP Overall (n=10)	17.1 ± 1.5	0.6 ± 0.2
SP02/05/09 Overall (n=3)	17.5 ± 2.0	0.7 ± 0.3
OA01	18.0 ± 1.6	0.5 ± 0.4
OA02	18.2 ± 0.8	0.7 ± 0.3
OA03	18.4 ± 1.5	0.5 ± 0.3
OA04	16.0 ± 2.3	0.6 ± 0.4
OA05	17.4 ± 0.9	0.4 ± 0.4
OA06	16.0 ± 2.3	1.1 ± 1.1
OA07	15.6 ± 1.1	0.6 ± 0.4
OA08	17.6 ± 2.1	0.8 ± 0.4
OA09	17.4 ± 0.5	1.9 ± 0.8
OA10	17.8 ± 2.4	0.4 ± 0.5
OA Overall (n=10)	17.2 ± 1.0	0.8 ± 0.4
OA02/05/09 Overall (n=3)	17.7 ± 0.5	1.0 ± 0.8
IS01	1.0 ± 1.2*	9.1 ± 1.8*
IS02	1.0 ± 1.2*	7.4 ± 0.9*
IS03	10.4 ± 6.0*	4.8 ± 3.3*
IS04	0.0 ± 0.0*	7.0 ± 5.8*
IS05	15.2 ± 0.4	1.7 ± 0.5
IS06	15.8 ± 2.3	0.4 ± 0.2
IS07	14.2 ± 2.0*	0.7 ± 0.5
IS08	13.8 ± 3.6*	2.7 ± 0.8
IS09	12.6 ± 3.8*	0.6 ± 0.5
IS10	10.0 ± 2.4*	0.2 ± 0.1
IS Overall (n=10)	9.4 ± 6.3*	3.5 ± 3.4
IS02/05/09 Overall (n=3)	9.6 ± 7.6*	3.2 ± 3.6
Control	18.8 ± 1.6	1.3 ± 1.6

a. n = 5
b. 20.0 = 100% survival. Asterisks denote values significantly less than (P=0.05) the control (West Beach, Whidbey Island, Washington), and are based on comparisons among 30 stations.
c. Number of amphipods on the surface per jar per day (out of a maximum of 20.0). Asterisks denote values significantly greater than (P=0.05) the control.

San Pablo Bay samples, -60 to +30 mV for the Oakland samples, -30 to +50 mV for the Islais Waterway samples and -150 to +20 mV for the controls.

3.2.2 Mussel larvae bioassay

Results of the mussel larvae bioassays are summarized in Table 3. Detailed results, including raw data, are provided in Appendix D.

Mean survival in the test sediments relative to the seawater control ranged from 51-83% for the San Pablo Bay samples, 24-49% for the Oakland samples, and 6-14% for the Islais Waterway samples. Relative survival in the sediment control was 73% of the seawater control. Results of the analysis of variance indicated that significant differences in survival occurred ($F=73.8$, $P=0.005$). All samples except for SP05 had significantly ($P=0.05$) lower survivals than the seawater and sediment controls. The Oakland and Islais Waterway sites had significantly ($P=0.05$) lower mean survival values than the seawater and sediment controls.

Mean percent abnormal larvae ranged from a low of 5.6% in the seawater control to a high of 67.7% in sample IS02. Mean percent abnormal larvae in both the seawater and sediment controls were well below the maximum 10% criterion for seawater set by ASTM (1985b). Results of the analysis of variance indicated that significant differences in mussel larvae abnormalities occurred ($F=40.6$, $P=0.005$). All Islais Waterway samples and samples OA05 and OA09 had significantly ($P=0.05$) higher abnormalities than the seawater control.

Water quality parameters during testing (Appendix C) ranged from: temperature, 18-20.5oC; salinity, 27-28 ppt; pH, 8.1-8.4; DO, 4.8-7.0 mg/L (all Islais Waterway samples had DO values less than 5.5 mg/L). These measurements are all within the water quality criteria set by ASTM (1985b) for bivalve larvae toxicity testing of seawater.

3.2.3 Clam reburial

Results of the Macoma balthica reburial tests are summarized in Table 4. Detailed results, including raw data, are provided in Appendix E. There were no clam mortalities in any of the test or control sediments over the 48 h exposure period.

In general, mean reburial rates (ET50 values) showed the following trend: fastest in San Pablo Bay sediment samples, slowest in Islais Waterway sediment samples and intermediate in Oakland sediment samples. However none of the differences between the test sediments were significantly ($P=0.05$) different from the control. The results of the analysis of variance were $F=2.44$, $0.025 < P < 0.05$. This lack of statistical difference is attributable to the fact that one of the five control replicates had the slowest reburial time of any of the sediments tested (ET50 = 13.0 min; control replicate A). In contrast the remaining four control replicates had some of the fastest reburial rates for any of the test groups. Re-analysis of the reburial values,

Table 3. Summary of mussel larvae bioassay results

Station	Mean Values ± S.D. a		
	Number of Larvaeb	Percent Survivalc	Percent Abnormald
SP02	288 ± 43*	56.9 ± 8.4	13.4 ± 2.8
SP05	418 ± 43	82.7 ± 8.6	7.7 ± 1.5
SP09	258 ± 60*	50.9 ± 11.8	15.3 ± 5.4
SP Overall (n=3)	321 ± 85	63.5 ± 16.9	12.1 ± 4.0
OA02	248 ± 46*	49.1 ± 9.0	14.5 ± 2.6
OA05	122 ± 26*	24.0 ± 5.2	24.7 ± 6.8*
OA09	170 ± 24*	33.5 ± 4.7	18.7 ± 8.4*
OA Overall (n=3)	180 ± 64*	35.5 ± 12.7	19.3 ± 5.1
IS02	30 ± 18*	6.0 ± 3.5	67.7 ± 8.9*
IS05	16 ± 16*	3.2 ± 3.0	65.9 ± 19.8*
IS09	70 ± 27*	13.9 ± 5.3	31.9 ± 5.2*
IS Overall (n=3)	39 ± 28*	7.7 ± 5.5	55.2 ± 20.2*
Seawater Control	506 ± 35	100.0 ± 6.9	5.6 ± 1.2
Sediment Control	371 ± 80	73.4 ± 15.8	7.4 ± 0.6

a. n = 5
b. Numbers of larvae surviving at the end of the test, which are used to determine relative survival and percent abnormal larvae. All values are significantly less than (P=0.05) the seawater control except SP Overall; asterisks denote values significantly less than (P=0.05) the sediment control.
c. Relative to the seawater control, which is assigned a mean value of 100%.
d. All values are significantly greater than (P=0.05) the seawater control except SP02, SP05, SP Overall, OA Overall, and the sediment control; asterisks denote values significantly greater than (P=0.05) the sediment control.

Table 4. Summary of Macoma balthica median reburial times (ET50s)

Sample	Replicate	ET50 (min)	$\bar{x}$ + S.D.
SP02	A	3.0	
	B	1.5	
	C	3.0	
	D	3.5	
	E	5.5	
			3.3 ± 1.4
SP05	A	2.0	
	B	5.0	
	C	3.0	
	D	6.5	
	E	2.0	
			3.9 ± 1.8
SP09	A	2.0	
	B	2.0	
	C	2.0	
	D	5.5	
	E	4.5	
			3.2 ± 1.7
OA02	A	4.5	
	B	2.5	
	C	4.0	
	D	4.0	
	E	3.0	
			3.6 ± 0.8
OA05	A	4.5	
	B	5.0	
	C	2.0	
	D	4.0	
	E	4.0	
			3.9 ± 1.1
OA09	A	2.5	
	B	5.0	
	C	6.0	
	D	9.0	
	E	6.5	
			5.8 ± 2.4
IS02	A	7.0	
	B	8.0	
	C	5.5	
	D	11.0	
	E	6.0	
			7.5 ± 2.2
IS05	A	7.0	
	B	7.5	
	C	5.0	
	D	10.0	
	E	5.5	
			7.0 ± 2.0
IS09	A	3.0	
	B	5.0	
	C	3.5	
	D	4.0	
	E	5.5	
			4.0 ± 1.2
Sediment Control	A	13.0	
	B	5.0	
	C	1.0	
	D	3.0	
	E	2.0	
			4.8 ± 4.8 (2.8 ± 1.7 for reps. B-E)

excluding all of the control data, showed that the reburial rates in samples IS02 and IS05 were significantly slower (P=0.05) than the rates in all other samples tested except OA09, which had a similarly slow reburial rate.

Water quality parameters during testing (Appendix E) ranged from: temperature, 15-16.5oC; salinity, 27-31 ppt; pH, 8.0-8.5; DO, greater than 4.7 mg/L except for sample IS02 which had a DO value of 3.6 mg/L.

3.2.4 Harpacticoid copepod bioassay

Results of the Tigriopus californicus reproductive success bioassays are summarized in Table 5. Detailed results, including raw data, are provided in Appendix F. There were no abnormalities observed in any of the test or control treatments over the four week exposure period. None of the test sediments prevented normal development from the nauplii to the more advanced copepodite form.

Compared to the other bioassays, the results of this testing were highly variable as exemplified by the high standard deviations (up to 50% of the means). Mean number of young produced per adult over four weeks ranged from 62.9 (SP09) to 181.0 (seawater control). The results of the analysis of variance indicated that some differences occurred in the number of young produced between the treatments ($F=1.88$, $0.05<P<0.1$). Production of young showed the same trend as survival of the adult females: San Pablo Bay and Islais Waterway sediments had significantly lower numbers of young produced (P=0.05) compared to the seawater control. In terms of individual stations, significantly (P=0.05) fewer young copepods were produced in samples IS02, IS05, IS09, SP02 and SP09 than in the seawater control.

The number of adult females surviving for four weeks out of a total of 8 seeded into the beakers ranged from 5 (62.5%) at Station SP02 to 8 (100%) at stations SP05, OA05 and OA09. Survival in the seawater control was 7 (87.5%). Lower mean survival occurred in San Pablo Bay and Islais Waterway sediments compared to Oakland sediments, but these differences were not significant at P=0.05.

Water quality parameters during testing (Appendix F) ranged from: temperature, 17-20oC; salinity, 30-35 ppt; pH, 7.8-8.5; DO, greater than 4.0 mg/L and generally greater than 4.5 mg/L.

3.3 Benthic Infaunal Analyses

3.3.1 Taxonomic analyses

Taxonomic analyses of the 45 grab samples resulted in the identification of a total of 70 taxa. Of these taxa, 36 were polychaete annelids, 10 were pelycepod molluscs, and 5 were amphipod crustaceans, while 19 were additional taxa of one or two species consisting of oligochaetes, turbellarians, sipunculids, ostracods, cumaceans, tanaids, decapods, brachyurans, pycnogonids, aeolid nudi-

Table 5. Summary of harpacticoid copepod bioassay results

Station	Mean Number of Young ± S.D. Produced Per Adult Over 4 Weeks[a]	Number of Adults Surviving to 4 Weeks[b]
SP02	107.5 ± 44.2*	5
SP05	121.2 ± 36.8	8
SP09	62.9 ± 33.1*	7
SP Overall (n=3)	97.2 ± 44.6*	6.7
OA02	112.0 ± 54.6	7
OA05	113.9 ± 52.6	8
OA09	118.8 ± 78.0	8
OA Overall (n=3)	114.9 ± 60.1	7.7
IS02	96.9 ± 37.3*	7
IS05	103.8 ± 48.6*	6
IS09	84.0 ± 35.3*	7
IS Overall (n=3)	95.3 ± 40*	6.7
Seawater Control	181.0 ± 132.6	7

a. Asterisks denote values significantly less than the control (P=0.05).
b. n=8 adults at start of testing.

branchs, ophiuroids, phoronids, and nemerteans. A complete list and classification for these taxa is provided in Table 6. Raw data on taxa abundances are provided in Appendix G.

Comparative data on the abundances of the five dominant taxa from each of the nine stations are provided in Table 7. The combined abundances of these dominant taxa accounted for over 95% of the total sample abundances. Presence/absence data are also included in Table 7 for common taxa that were not numerically dominant at particular stations.

Differences (and similarities) in the occurrence of taxa among the sites were observed. For instance, the San Pablo Bay and Oakland sites had roughly similar faunal assemblages, whereas distinct faunal assemblages were found in the Islais Waterway site. The benthic tube-dwelling amphipod Ampelisca abdita was by far the most numerically dominant taxon at all Oakland and San Pablo Bay stations, but it was rare at the Islais Waterway site. The polychaete Streblospio benedicti and the bivalve mollusc Macoma nasuta were only found in Islais Waterway.

Generally, the Oakland site was dominated by gammarid amphipods (3 of 5 dominants) with one or two incidental polychaete taxa. The San Pablo Bay reference site was dominated by a single amphipod, Ampelisca abdita, but the other four dominant taxa were polychaetes. The Islais Waterway site was generally depauperate. This site was dominated by the polychaete Capitella capitata, with incidental occurrence of polychaete, oligochaete and bivalve mollusc species.

Use of the 1.0 mm sieve for screening the marine sediments during collection eliminated the possibility of including the meiofaunal marine Oligochaeta in the quantitative analysis of these benthic communities. The few specimens found were likely collected incidentally, probably being associated with sample debris not eliminated during the field processing of these samples. However, the distribution of this group is discussed in qualitative terms, and they are included in Table 6.

3.3.2 Community descriptive analyses

Table 8 provides the following community descriptive parameters for each of the 45 benthic samples: number of taxa (=species richness, S), Shannon-Weiner diversity index (H), Pielou's equitability index (J), total sample abundance, and a measure of numerical dominance - the complement of equitability (1-J). Examination of these data indicates that there is a relatively high degree of within-station variability associated with each of these parameters. Species richness and total abundance for station SP02, for example, ranged from 3 to 8 species and 18 to 1,281 individuals. Even with this variability, between-site differences were quite apparent, with Islais Waterway stations generally having very low species richness and total numbers of individuals while the San Pablo Bay and Oakland sites showed progressively greater values for these variables.

Table 6. Benthic invertebrate taxa identified from San Franciso Bay

---

Coelenterata
  Anthozoa
    Ceriantharia
      Cerianthidae
        Pachycerianthus fimbriatus (McMurrich)

Nemertea

Platyhelminthes
  Turbellaria

Annelida
  Oligochaeta
    Tubificida
      Tubificidae
        Limnodriloides victoriensis Brinkhurst and Baker
        Tubificoides brownae Brinkhurst and Baker
        Tubificoides wasselli Brinkhurst and Baker
  Polychaeta
    Orbiniida
      Orbiniidae
        Leitoscoloplos pugettensis (Pettibone)

    Spionida
      Spionidae
        Polydora brachycephala Hartmann
        Scolelepsis squamata (Muller)
        Streblospio benedicti Webster

      Cirratulidae
        Chaetozone ?*acuta* Banse and Hobson

    Cossurida
      Cossuridae
        Cossura soyeri Laubier

    Capitellida
      Capitellidae
        Barantolla americana Hartmann
        Capitella capitata (Fabricius)
        Heteromastus filiformis (Claparede)
        Mediomastus californiensis Hartman
        Notomastus tenuis Moore

      Maldanidae
        Asychis sp.

Table 6 Continued

Opheliida
Opheliidae
Armandia brevis (Moore)

Terebellida
Ampharetidae
Melinna oculata (Banse)

Terebellidae
Amaena occidentalis (Hartmann)

Sabellida
Sabellidae
Euchone analis (Kroyer)

Phyllodocida
Polynoidae
Harmothoe imbricata (Linnaeus)

Sigalionidae
Pholoe minuta (Fabricius)

Phyllodocidae
Anaitides longipes (Berkeley)

Hesionidae
Gyptis brevipalpa (Hartmann-Schroder)

Pilargidae
Sigambra bassi Hartmann

Syllidae
Sphaerosyllis pirifera Claparede

Nereidae

Nephtyidae
Nephtys sp.
N. caecoides Hartmann
N. californiensis Hartmann
N. cornuta Berkeley and Berkeley
N. ferruginea Hartmann

Clyceridae
Glycera sp.
G. americana Leidy
G. capitata Oersted
G. convoluta Keferstein

Goniadidae
Glycinde picta Berkeley

Table 6 Continued

- Eunicida
  - Lumbrineridae
    - *Lumbrineris* sp.
  - Dorvilleidae
    - *Schistomeringos rudolphi* (Fauchald)
- Phoronida
  - Phoronidae
    - *Phoronis* sp.
- Sipunculida
  - Golfingiidae
    - *Golfingia hespera* Chamberlain
- Mollusca
  - Bivalvia
    - Veneroida
      - Cardiidae
        - *Clinocardium fucanum* (Dall)
      - Solenidae
        - *Solen sicarius* Gould
      - Tellinidae
        - *Macoma expansa* Carpenter
        - *M. nasuta* Conrad
      - Veneridae
        - *Protothaca staminea* (Conrad)
        - *Tapes philippinarum* Adams and Reeve
        - *Transenella tantilla* Gould
    - Myoida
      - Myidae
        - *Cryptomya californica* (Gould)
    - Pholadomyoida
      - Lyonsiidae
        - *Lyonsia californica* Gould
    - Mytiloidea
      - Mytilidae
        - *Musculus senhousia* (Benson)
  - Gastropoda
    - Opisthobranchia
      - Aeolidea
- Arthropoda
  - Crustacea
    - Ostracoda
      - Sarsiellidae
        - *Sarsiella zostericola* Cushman

Table 6 Continued

- Tanaidacea
  - Paratanaidae
    - *Leptochelia* sp.
- Cumacea
  - Leuconidae
    - *Eudorella pacifica* Hart

- Amphipoda
  - Gammaridea
    - Ampeliscidae
      - *Ampelisca* ?*hessleri* Dickinson
      - *A. abdita* Barnard
    - Corophiidae
      - *Corophium* sp.
      - *Photis californica* Stout
    - Caprellidae
      - Caprellidae
        - *Caprella* sp.

- Decapoda
  - Thalassinoida
    - Callianassidae
      - *Callianassa gigas* Dana
  - Brachyura
    - Pinnotheridae
      - *Pinnixa* sp.
      - *Schleroplax granulata* Rathbun
    - Cancridae
      - *Cancer gracilis* Dana
  - Pycnogonida
    - Ammotheidae
      - *Achelia nudiuscula* (Hall)

- Echinodermata
  - Ophiuroidea
    - Ophiurida
      - Amphiuridae

- Chordata
  - Urochordata
    - Ascidiacea

Table 7. Five most abundant taxa present at each station

Taxa	- Oakland - OA02	OA05	OA09	- San Pablo Bay - SP02	SP05	SP09	- Islais Waterway - IS02[a]	IS05	IS09
Photis californica (c)*	19[b]	60	102	+		+			
Leptochelia sp. (c)	17	+	44						
Phoronis sp.(ph)	+	84	18		2	+			
Euchone analis (po)	12	16	+	+	+	+		+	
Harmothoe imbricata (po)	22	15	19	+	14	14	+		
Ampelisca abdita (c)	2882	3522	3402	575	337	806	1	+	+
Corophium sp. (c)	+	+	+	52	2	13			
Asychis sp. (po)	+	+	+		6	4			
Glycinde picta (po)	+	+	+	2	3	12		+	4
Capitella capitata (po)		+				+	46	58	
Macoma nasuta (m)									2
Nephtys caecoides (po)						+			1
Streblospio benedicti (po)									1
Macoma expansa (m)		+	+		+	+			1
Tubificoides brownae (o)					+			+	+
Platyhelminthes		+		1		+			

a. This station has only five taxa present.
b. Truncated (non-decimal) mean abundance (no. of individuals) values per 0.1 m^2; + indicates occurrence at a station, but not as one of the five dominant taxa at that station.

* po = Polychaeta
c = Crustacea
m = Mollusca
ph = Phoronida
o = Oligochaeta

Table 8. Taxa richness, diversity, evenness and dominance measures for each sample

Site	Station	Replicate	S	H	J	1-J	Total Abundance
San Pablo Bay	02	1	6	0.21	0.28	0.72	505.
		2	8	0.17	0.19	0.81	918.
		3	8	0.23	0.25	0.75	461.
		4	8	0.08	0.09	0.91	1281.
		5	3	0.37	0.77	0.23	18.
	05	1	11	0.21	0.20	0.80	483.
		2	11	0.30	0.29	0.71	169.
		3	9	0.33	0.35	0.65	139.
		4	7	0.23	0.28	0.72	438.
		5	11	0.14	0.13	0.87	643.
	09	1	17	0.20	0.17	0.83	685.
		2	12	0.17	0.16	0.84	936.
		3	13	0.28	0.25	0.75	409.
		4	17	0.15	0.12	0.88	1116.
		5	13	0.13	0.11	0.89	932.
Oakland	02	1	12	0.12	0.11	0.89	6416.
		2	11	0.11	0.10	0.90	1797.
		3	15	0.17	0.15	0.85	2567.
		4	17	0.17	0.14	0.86	1536.
		5	8	0.09	0.10	0.90	2804.
	05	1	19	0.32	0.25	0.75	2942.
		2	13	0.11	0.10	0.90	5417.
		3	12	0.17	0.16	0.84	2801.
		4	18	0.15	0.12	0.88	4250.
		5	9	0.12	0.13	0.87	3528.
	09	1	21	0.22	0.16	0.84	3525.
		2	14	0.19	0.16	0.84	4616.
		3	14	0.16	0.14	0.86	3394.
		4	16	0.15	0.12	0.88	3452.
		5	18	0.23	0.18	0.82	3482.
Islais Waterway	02	1	3	0.24	0.51	0.49	18.
		2	3	0.08	0.16	0.84	56.
		3	3	0.08	0.16	0.84	58.
		4*	1	--	--	--	1.
		5	2	0.02	0.08	0.92	103.
	05	1	3	0.14	0.30	0.70	26.
		2*	1	--	--	--	24.
		3	2	0.02	0.07	0.93	114.
		4	2	0.07	0.22	0.78	56.
		5	2	0.05	0.17	0.83	77.
	09	1	8	0.74	0.82	0.18	22.
		2	11	1.00	0.96	0.04	16.
		3	6	0.72	0.93	0.07	8.
		4	9	0.89	0.93	0.07	20.
		5	7	0.82	0.97	0.03	9.

Legend:
S = number of taxa
H = Shannon-Wiener diversity
J = Pielou's equitability
1-J = numerical dominance

Total Abundance = numbers of individuals per 0.1 m^2

* Only one taxon collected.

Table 9 summarizes the number of taxa, diversity and dominance for each station (n=5) and for each site (n=15). Significant variability is apparent both within and between sites, based on the standard errors. The same general trends noted in Table 7 were observed, with Islais Waterway stations generally much more depauperate in terms of total numbers of individuals and species richness.

Of the three Islais Waterway stations, IS09 was anomalous. This station had the highest species richness, the highest sample diversity and the lowest dominance. Species diversity was, in fact, higher than at any of the other stations in any site by an approximate factor of 4.

The Oakland and San Pablo Bay sites both had very high mean numerical dominance values and high total sample abundances. Large numbers of the amphipod Ampelisca abdita within these sites, but not within the Islais Waterway site, accounted for the observed differences in diversity. Highest mean diversity occurred at the Islais Waterway site, solely as a result of the anomalously high values for IS09.

Figure 20 illustrates the relationship between species richness and total abundance for each station and for each site. The solid bars represent sample standard errors and the dotted bars are 95% confidence limits. This figure demonstrates the high degree of variability among stations at any one of the study sites and at the same time illustrates the effect of a larger sample size (n=15) on reducing such between-station variability (compare standard error bars for sites and those for stations).

Station IS09 is once again shown as anomalous compared to IS02 and IS05. Although the low total number of individuals found at IS09 was characteristic of the Islais Waterway site, species richness was much higher, and was actually not significantly different (P=0.05) than those stations comprising the San Pablo Bay site.

Figure 21 demonstrates the strong positive correlation between species richness and numerical dominance. The reduction in the width of the error bars from Islais Waterway to San Pablo Bay and then to Oakland clearly illustrates decreasing variability in within-station replicates among these sites.

3.3.3 Proportions of major taxonomic groups

Table 10 and Figure 22 summarize the mean proportions of major taxonomic groups between stations and between sites. These proportions, expressed here as percentages, were calculated for each replicate and then statistically summarized (mean ± standard error) for each station (n=5) and overall for each site (n=15).

These data complement the results of the previous analyses by showing which taxonomic groups are dominant at each of the stations and sites. Gammarid amphipods represented the dominant group within

Table 9. Summary of infauna community descriptive parameters

Site	Station	S		H		I-J		Total Abundance	
San Pablo Bay	02	6.6	(0.98)[b]	0.21	(0.05)	0.68	(0.12)	637	(215.1)
	05	9.8	(0.80)	0.24	(0.03)	0.75	(0.04)	374	(96.3)
	09	14.4	(1.08)	0.19	(0.03)	0.84	(0.02)	816	(122.6)
Oakland	02	12.6	(1.57)	0.13	(0.02)	0.88	(0.01)	3024	(879.9)
	05	14.2	(1.88)	0.17	(0.04)	0.85	(0.03)	3788	(480.9)
	09	16.6	(1.32)	0.19	(0.02)	0.85	(0.01)	3694	(231.5)
Islais Waterway	02	2.4	(0.40)	0.08	(0.04)	0.62	(0.17)	47	(17.7)
	05	2.0	(0.32)	0.06	(0.02)	0.65	(0.17)	59	(16.8)
	09	8.2	(0.86)	0.83	(0.51)	0.08	(0.03)	15	(2.8)
San Pablo Bay Overall[a]		10.3	(1.00)	0.21	(0.02)	0.76	(0.04)	609	(95.2)
Oakland Overall[a]		14.5	(0.97)	0.17	(0.02)	0.86	(0.01)	3502	(330.3)
Islais Waterway Overall[a]		4.2	(0.82)	0.33	(0.10)	0.45	(0.10)	41	(9.1)

a. Data from all replicate grabs from each site were used for this analysis (n=15).
b. Values represent means, with sample standard errors in brackets (n=5).

Legend:
S = number of taxa
H = Shannon-Wiener diversity
I-J = numerical dominance.
Total Abundance = numbers of individuals per 0.1 m^2.

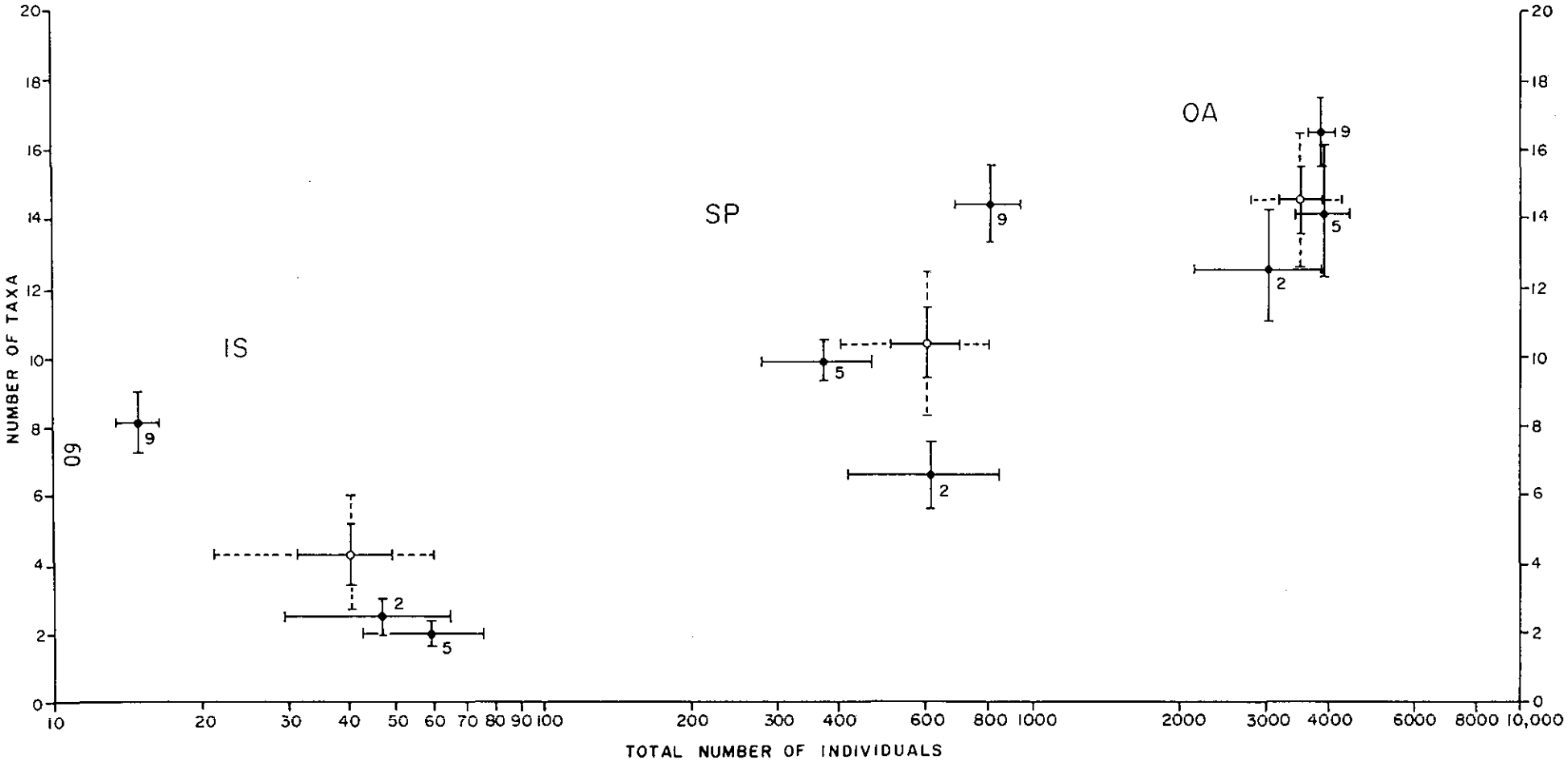


Figure 20. Mean taxa richness plotted against mean total abundance. Solid bars represent standard errors. Extended (dashed) bars represent 95% confidence limits for sites. Solid circles are individual stations (n=5); open circles are sites (n=15).

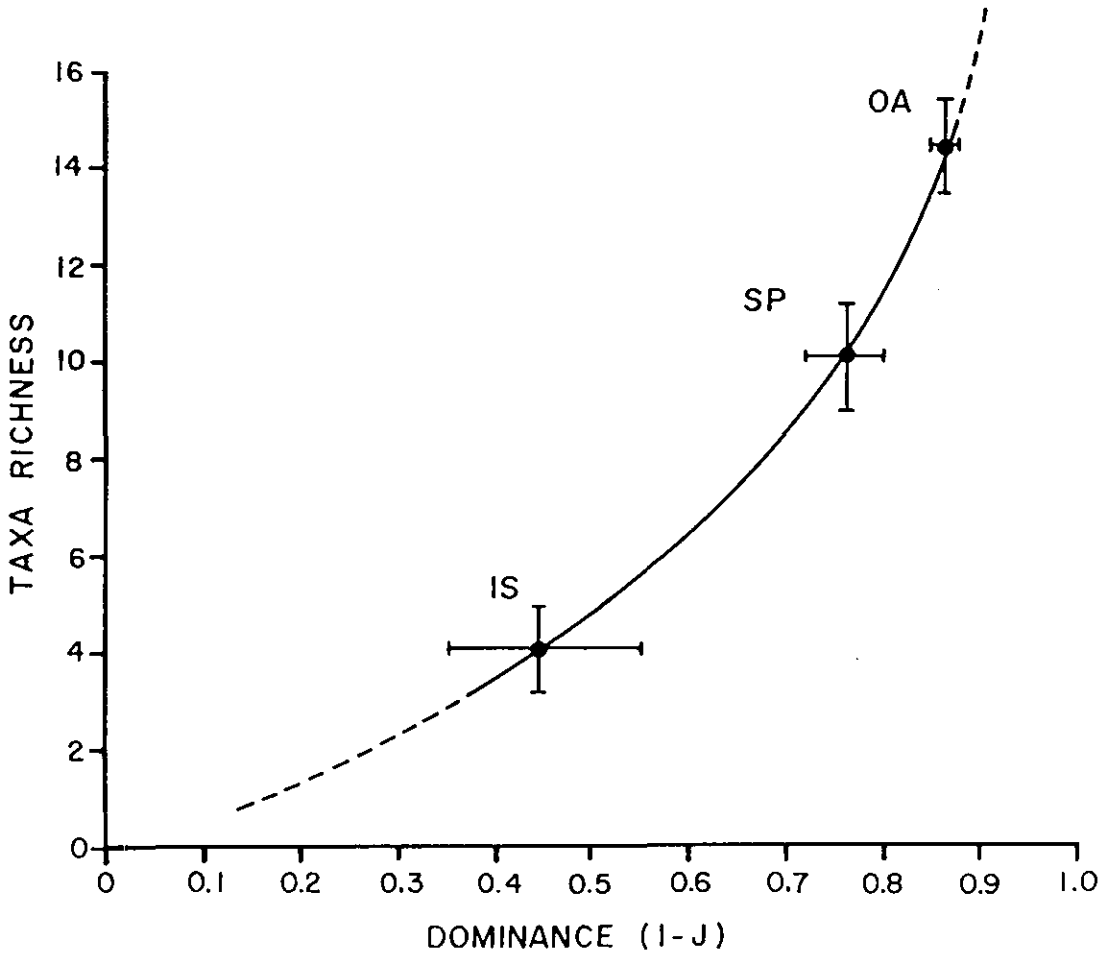


Figure 21. Taxa richness/dominance relationship based on mean data for each site. Means and standard errors are provided (n=15).

Table 10. Mean proportions of major taxonomic groups expressed as a percentage of total abundance

Site	Station	Polychaeta		Amphipoda		Mollusca		Others	
San Pablo Bay	02	7.28	(6.51)[b]	92.40	(6.43)	0.08	(0.05)	0.22	(0.09)
	05	8.44	(1.24)	89.06	(1.95)	0.24	(0.17)	0.28	(1.04)
	09	5.16	(1.25)	94.18	(1.19)	0.04	(0.04)	0.62	(0.13)
Oakland	02	2.46	(0.45)	96.30	(0.56)	0.00	(0.00)	1.22	(0.32)
	05	1.80	(0.25)	94.74	(2.52)	0.12	(0.06)	3.36	(2.30)
	09	1.58	(0.17)	96.28	(0.39)	0.10	(0.01)	2.04	(0.23)
Islais Waterway	02	96.52	(1.99)	3.48	(1.99)	0.00	(0.00)	0.00	(0.00)
	05	98.46	(1.54)	1.54	(1.54)	0.00	(0.00)	0.00	(0.00)
	09	58.02	(4.59)	8.72	(3.87)	30.52	(5.84)	2.72	(2.72)
San Pablo Bay Overall[a]		6.96	(2.11)	91.88	(2.18)	0.12	(0.06)	1.04	(0.40)
Oakland Overall[a]		1.94	(0.20)	95.77	(0.83)	0.07	(0.03)	2.21	(0.76)
Islais Waterway Overall[a]		84.33	(5.23)	4.58	(1.64)	10.17	(4.25)	0.91	(0.91)

a. Data from all replicate grabs from each site were used for this analysis (n=15).
b. Values represent means, with sample standard errors in brackets (n=5).

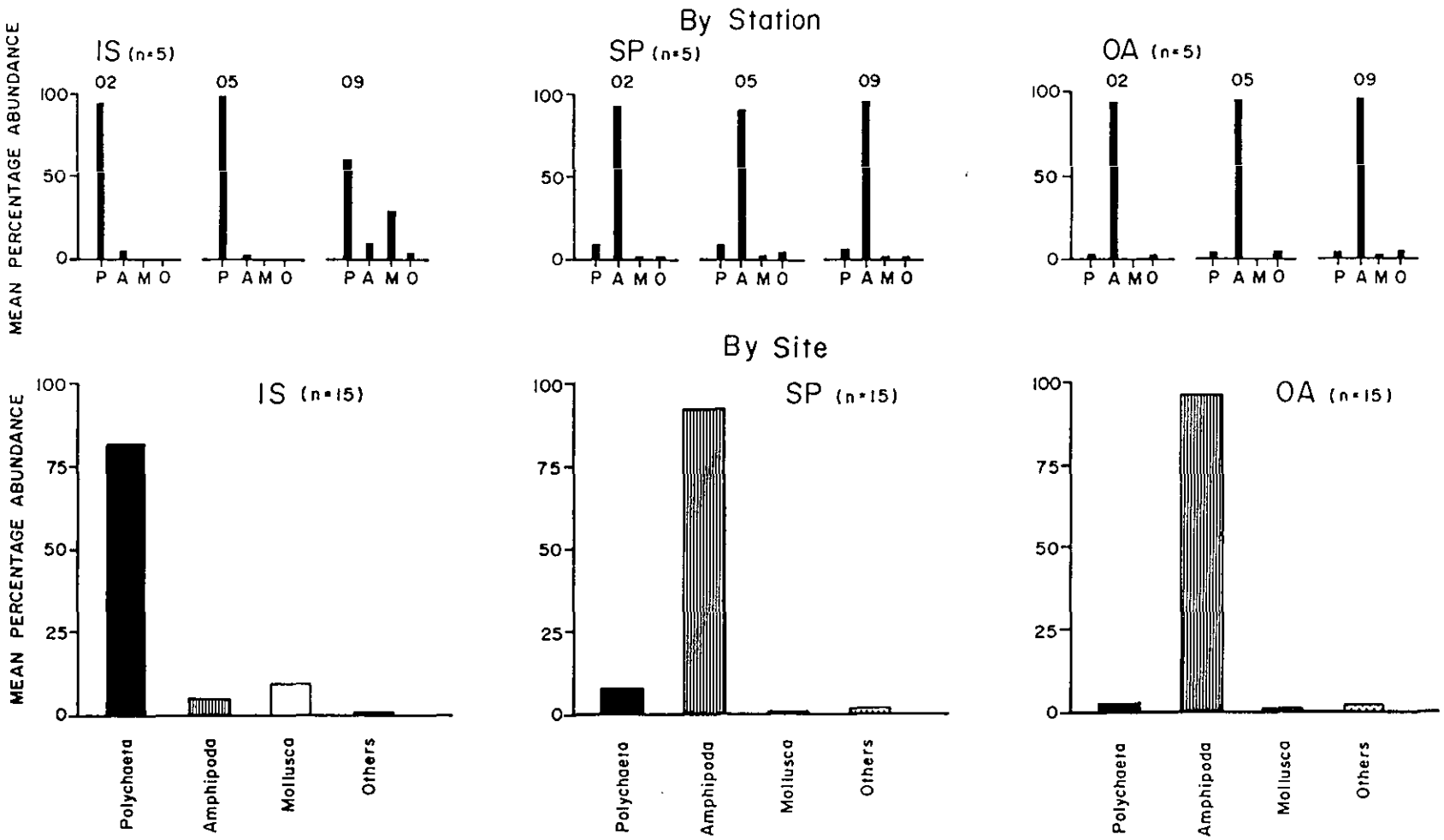


Figure 22. Proportions of major taxa present at each station and at each site.

both of the Oakland and San Pablo Bay sites with one species, Ampelisca abdita, contributing over 98% of the combined amphipod abundance in each case.

The Islais Waterway site had a mean amphipod component of less than 5% of the total sample abundance. In contrast, whereas the polychaetes constituted less than 7% of the total fauna in the Oakland and San Pablo Bay sites, this taxonomic group comprised over 80% of the total sample abundance within the Islais Waterway site. This group was dominated by a single species, Capitella capitata, which comprised over 95% of the polychaetes present.

The following table documents the numerical differences between Ampelisca abdita and Capitella capitata for the three sites. Results represent mean abundances (n=15) with standard errors in parentheses.

Site	Mean Nos. per Grab (0.1m2) Ampelisca abdita	Capitella capitata
OA	3,269.2 (320.9)	3.20 (1.71)
SP	573.3 (94.3)	0.13 (0.10)
IS	0.7 (0.2)	34.53 (10.06)

It is interesting to note that although the Islais Waterway site had significantly (P=0.05) greater numbers of C. capitata than any other site, this value would have been even higher were it not for station IS09 which had no C. capitata. Other stations within this site, IS05 for example, had replicate 0.1 m2 grabs containing in excess of 100 of these animals.

3.3.4 Cluster analyses

Figures 23 and 24 summarize the results of an unweighted pair-group clustering of stations (using mean values, n=5) and sites (using mean values, n=15) based on between-site similarities, as calculated using the Bray-Curtis coefficient. Cluster analyses were performed using mean values at sites and stations in order to effectively increase the sample size and incorporate the majority of the taxa representative of the resident benthic community. Analysis by replicate was performed but not reported as these analyses obscured between-station and between-site trends, and merely showed that there was a high degree of between-replicate variability, particularly at the Islais Waterway and San Pablo Bay sites.

Figure 23 illustrates the degree of benthic infaunal similarity between samples collected at stations within any one site. All Oakland stations clustered together, with an overall similarity of 80%. Stations within San Pablo Bay showed a similar affinity, with between-station similarity of at least 77%. Islais Waterway stations, however, did not show the same high similarities. Although stations IS02 and IS05 had a similarity of 90%, station IS09 had a similarity

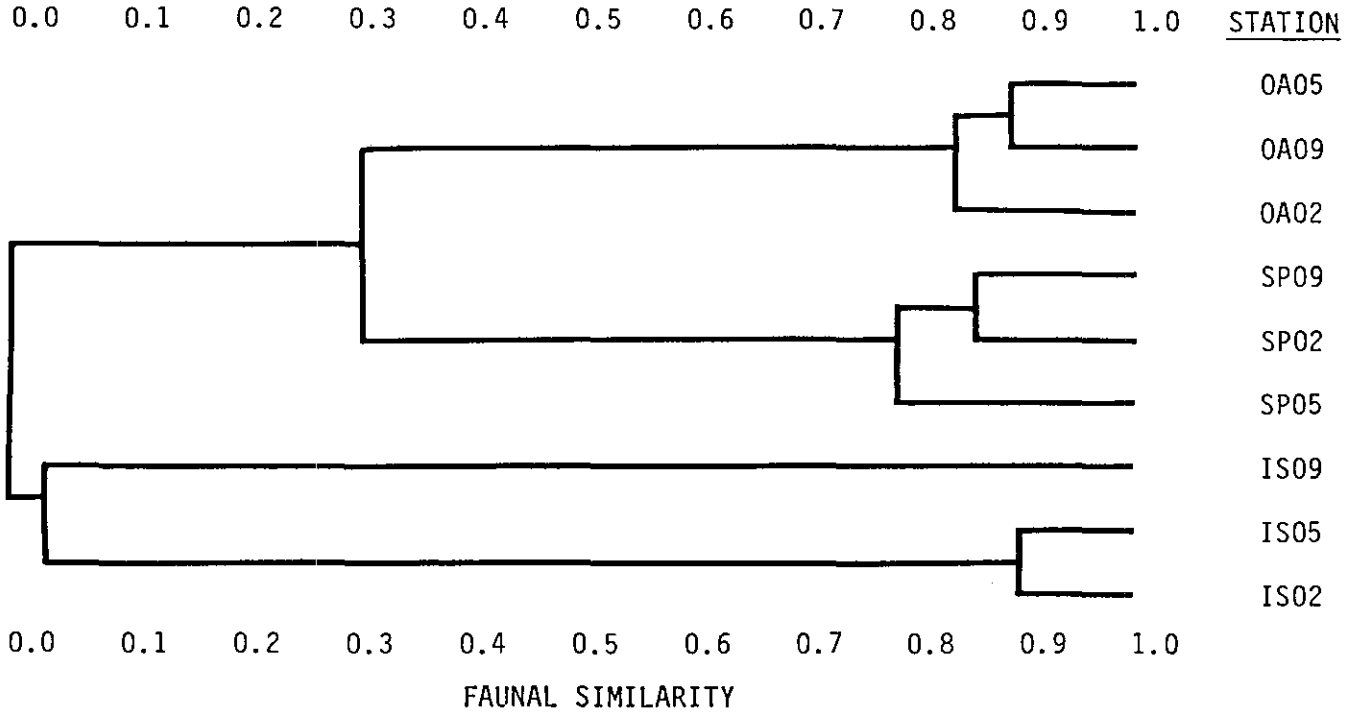


Figure 23. Results of between-station cluster analysis. Similarities based on sample means (n=5).

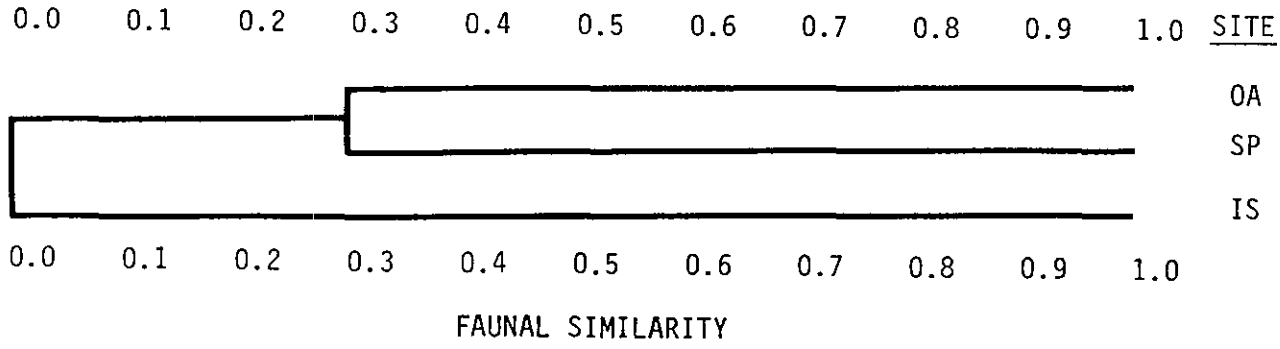


Figure 24. Results of between-site cluster analysis. Similarities based on sample means (n=15).

level of 0 to 6% with stations IS02 and IS05, respectively. This result is consistent with previous analyses which have revealed a consistent dissimilarity between IS09 and the other two Islais Waterway stations.

Figure 23 also shows that Oakland stations are much more similar to San Pablo Bay than to the Islais Waterway stations. Islais Waterway stations had a similarity with all of the other stations of less than 3%.

Figure 24 summarizes the results of the same cluster analysis performed for pooled between-site (n=15) species abundance data. Trends observed for the between-station analysis are duplicated. San Pablo Bay and Oakland are approximately 30% similar, while Islais Waterway is less than 1% similar to these areas.

3.3.5 Ratios-to-reference (RTR)

The relative degree of difference of various infauna parameters at each station and each site, compared to the mean values for these parameters at the San Pablo Bay reference site was calculated as Ratio-to-Reference (RTR) values. This RTR criterion served to normalize the data and was based on (but not dependent on) the assumption that the benthic infauna at the San Pablo Bay site were unaltered by pollution. Presentation of the data as RTR values provides a measure of the degree of alteration at each station and site compared to the reference site, and to each other.

Table 11 lists the San Pablo Bay (SP) reference parameters used to calculate RTR values for each of the other stations and sites. Tables 12 and 13 provide a summary of RTR values (means $\pm$ standard errors) for stations (n=5) and for sites (n=15 for each site).

The RTR values show that parameters measured for stations within the Oakland site were, except for diversity and proportion of polychaetes, slightly higher than reference. Parameters measured for stations within the Islais Waterway site were typically much lower than reference, except for the proportion of Polychaeta and Mollusca, which were much higher. The mean diversity (n=15) for the Islais Waterway site suggests that it is higher than reference, but examination of individual station values (n=5) reveals that station IS09 has skewed this mean value and without station IS09 this value would be much lower. The dissimilarity of station IS09 from the other Islais Waterway stations is shown through each of the calculated parameters. For example, proportion of Mollusca at IS09 (Table 13) is 254.3 times that of reference whereas IS02 and IS05 both have zero values. In fact, the next highest RTR value for proportion of Mollusca is only 2.0 at SP05.

3.3.6 Log-normal goodness-of-fit

Table 14 documents the distribution of species among geometric classes of individuals (i.e., numbers of species represented by different numbers of individuals in the samples). As this analysis is effective only when applied to a large, heterogeneous sample, it was performed

Table 11. Mean San Pablo Bay (SP) reference infauna parameters for Ratio-to-Reference (RTR) determinations

Parameter	Mean	Standard Error
Species Richness	10.27	1.00
Diversity	0.21	0.02
Dominance (1-J)	0.76	0.04
Total Abundancea	608.90	95.22
% Polychaeta	6.96	2.11
% Amphipoda	91.88	2.18
% Mollusca	0.12	0.06
% Others	1.04	0.40

a. Numbers of individuals per 0.1 m^2.

Table 12. Ratios between mean reference site (SP) values and individual station and site values for community descriptive parametersa

Site	Station	Species Richness		Diversity		Numerical Dominance		Total Abundance	
San Pablo Bay	02	0.64	(0.10)	1.01	(0.22)	0.90	(0.16)	1.05	(0.35)
	05	0.95	(0.08)	1.15	(0.16)	0.99	(0.05)	0.61	(0.16)
	09	1.40	(0.10)	0.89	(0.12)	1.10	(0.03)	1.34	(0.20)
Oakland	02	1.23	(0.15)	0.63	(0.08)	1.16	(0.01)	4.97	(1.44)
	05	1.38	(0.18)	0.83	(0.18)	1.12	(0.03)	6.22	(0.79)
	09	1.62	(0.13)	0.90	(0.08)	1.12	(0.01)	6.07	(0.38)
Islais Waterway	02	0.23	(0.04)	0.40	(0.20)	0.81	(0.23)	0.08	(0.03)
	05	0.19	(0.03)	0.27	(0.07)	0.85	(0.22)	0.10	(0.03)
	09	0.80	(0.08)	3.97	(0.24)	0.10	(0.04)	0.02	(0.01)
San Pablo Bay Overall[b]		.....Reference Site.....RTR = 1.0							
Oakland Overall[b]		1.41	(0.09)	0.79	(0.07)	1.13	(0.01)	5.75	(0.54)
Islais Waterway Overall[b]		0.41	(0.08)	1.54	(0.47)	0.59	(0.13)	0.07	(0.01)

a. Mean RTR values are provided with standard errors in brackets.
1.0 = no difference from reference.
<1.0 = variable depressed from reference by a factor equal to the RTR value.
>1.0 = variable enhanced from reference by a factor equal to the RTR value.

b. Mean data from all replicate grabs were used for this analysis.

Table 13. Ratios between mean reference site (SP) values and individual station and site values for major taxonomic group proportions[a]

Site	Station	Polychaeta		Amphipoda		Mollusca		Others	
San Pablo Bay	02	1.05	(0.94)	1.01	(0.07)	0.67	(0.41)	0.21	(0.09)
	05	1.21	(0.18)	0.97	(0.02)	2.00	(1.46)	2.19	(1.00)
	09	0.74	(0.18)	1.02	(0.01)	0.33	(0.33)	0.60	(0.13)
Oakland	02	0.35	(0.06)	1.05	(0.01)	0.00	(0.00)	1.17	(0.30)
	05	0.26	(0.36)	1.03	(0.03)	1.00	(0.49)	3.23	(2.21)
	09	0.23	(0.02)	1.05	(0.01)	0.83	(0.37)	1.96	(0.22)
Islais Waterway	02	13.87	(0.29)	0.04	(0.02)	0.00	(0.00)	0.00	(0.00)
	05	14.15	(0.22)	0.02	(0.02)	0.00	(0.00)	0.00	(0.00)
	09	8.34	(0.66)	0.10	(0.04)	254.3	(48.69)	2.62	(2.62)
San Pablo Bay Overall[b]		.....Reference Site.....RTR = 1.0.....							
Oakland Overall[b]		0.28	(0.03)	1.04	(0.10)	0.61	(0.22)	2.12	(0.73)
Islais Waterway Overall[b]		12.12	(0.75)	0.05	(0.02)	84.78	(35.39)	0.87	(0.87)

a. Mean RTR values are provided with sample standard errors in brackets.
1.0 = no difference from reference.
<1.0 = variable depressed from reference by a factor equal to the RTR value.
>1.0 = variable enhanced from reference by a factor equal to the RTR value.

b. Mean data from all replicate grabs were used for this analysis.

Table 14. Summary of infauna log-normal analysisa

Site	- Geometric Class - 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
San Pablo Bay	10	7	9	6	2	1	1	1	1				1			
Oakland			11	9	4	5	4	3	2	2						1
Islais Waterway	6	5	5	2	1					1						

a. Values within the table represent the number of taxa, with the corresponding numbers of individuals defined by the appropriate Geometric Class. For example:

Geometric Class	Individual(s)
1	1
2	2-3
3	4-7
4	8-15
5	16-31
6	32-63

To explain further, note that San Pablo Bay has ten taxa which are represented by only one individual. It has seven taxa with two to three individuals, nine taxa with four to seven individuals, and so on.

using the pooled data from each of the study sites. Oakland had the majority of species in geometric classes 3 and 4, represented by species with abundances of 4-15 individuals each. The high degree of dominance demonstrated previously for this site is further supported by the occupation of outlying geometric class 16 (a species with abundances of 32,000 individuals per m2, i.e. Ampelisca abdita). San Pablo Bay and Islais Waterway also displayed outlying geometric classes, at 13 and 10, respectively. The San Pablo Bay outlier is characterized by Ampelisca abdita, while the Islais Waterway outlier is represented by Capitella capitata. Ignoring the single geometric class which contains the dominant taxon, each site differs from the others in the number of geometric classes spanned. The Oakland site extends through class 16, but has no taxa within the first two classes, which comprise the incidental taxa. The San Pablo Bay site covers classes 1-13, with the majority of taxa present within the first four classes. The Islais Waterway site spans classes 1-10, with 80% of the taxa occurring in the first 3 classes.

An attempt at graphically fitting the log-normal distribution (as per Gray and Mirza, 1979) is provided in Figure 25. The number of each species within the respective geometric classes is represented as a cumulative percentage on a probit scale. If a log-normal distribution existed, this plot would yield a straight line. Due primarily to the substantial dominance in each of the study sites, these curves deviate from the ideal log-normal plot.

4.0 DISCUSSION

In the following sections detailed data analyses are conducted aimed at testing and evaluating not only the Sediment Quality Triad components and the Triad itself, but also approaches to combining data from the Triad for display and discussion.

4.1 Sediment Physical and Chemical Characteristics

4.1.1 Spatial distributions

While nearly all of the sediment samples appeared similar in texture during the field collection, only the Oakland site had physical and chemical characteristics that were of low variability among the stations. Variability in texture, Eh, organic matter content and sulfides among the stations, particularly at the other sites, made it difficult to resolve effects in the benthic community study component that may have been associated specifically with toxic chemicals in these sediments. The data were interesting in themselves, however, because of the strong relationship observed between the grain size and TOC content of the sediments and between those two parameters and the concentrations of a number of chemical substances. Such linear relationships are not often observed in studies of natural systems and they may simply reflect an artifact of fortuitous sampling with very limited numbers of samples. If these data do reflect true conditions in the Bay, they could indicate a very well mixed depositional regime. The latter possibility gains some credence from other studies that have shown that because San Francisco Bay is a shallow system with strong tidal and wind-induced currents, its mixing/flushing rates, even

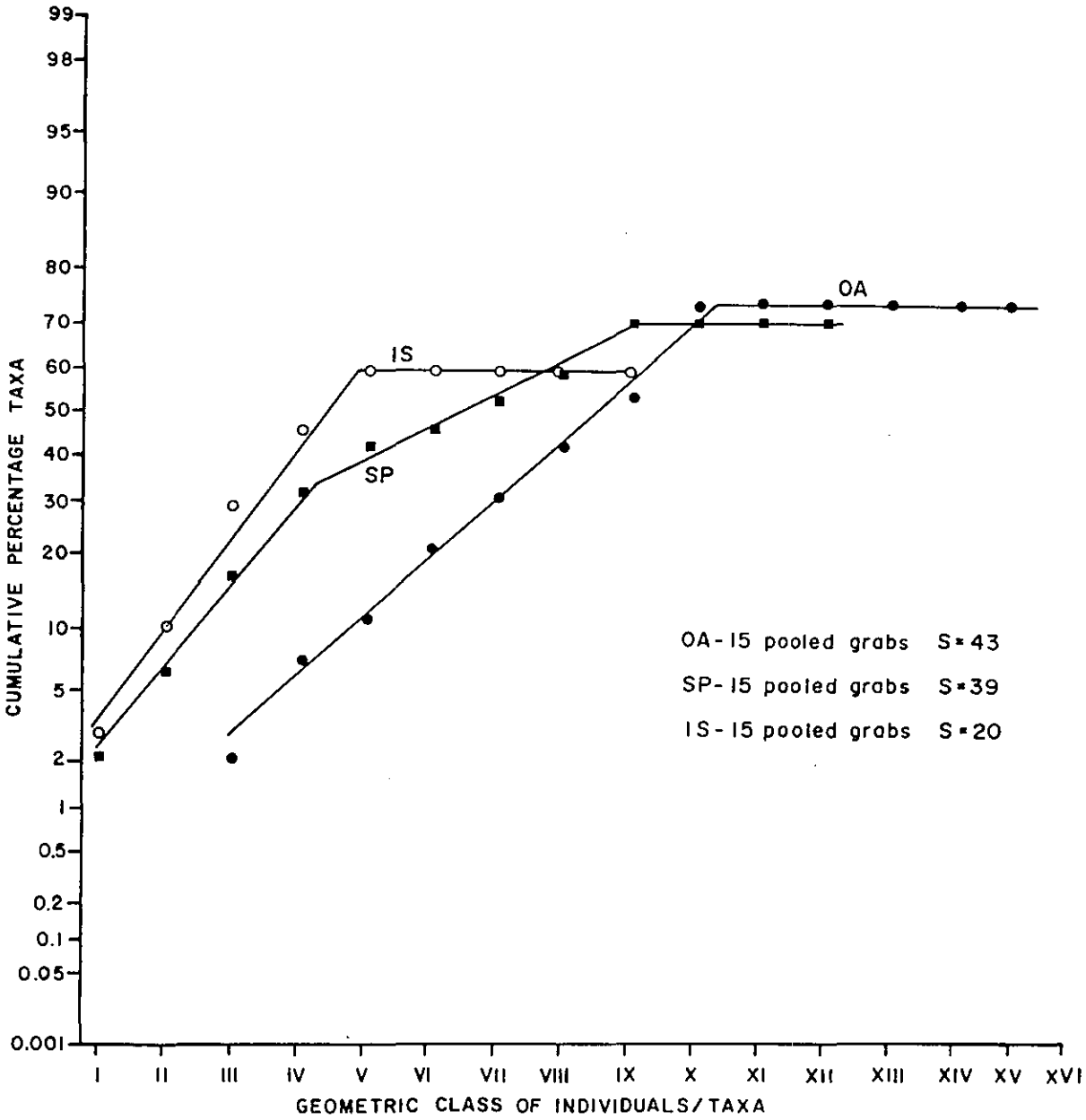


Figure 25. Graphic presentation of log-normal analysis.

in the south end of the Bay, are not long compared to the life times of the chemical substances in the sediments (McCulloch et al., 1970; Nichols et al., 1986). Thus, it is possible that the Bay is relatively well mixed and flushed, at least compared to the time that was probably required to deposit the sediments collected for this study.

On the other hand, the substances identified as being particularly enriched at the Islais Waterway site (i.e., lead, mercury, tin, silver, the LPAH, the HPAH, coprostanol, DDTs and PCBs) present an interesting suite of compounds. These compounds have all been implicated in studies from other areas as major contaminants in combined municipal sewage and street runoff (Romberg et al., 1984; Tetra Tech, 1985).

4.1.2 Comparisons with other San Francisco Bay data

Only two other studies were located that provided at least some recent data regarding the concentrations of the substances of interest to this study. Spies et al. (1985) measured PAH compounds, DDTs and PCBs at a number of sites including ones near both the San Pablo Bay and Oakland sites sampled during the present study. The data reported, however, presented substantially greater concentrations for the measured compounds. The PAH sediment concentrations reported by Spies et al. (1985) were for a slightly different group of compounds but the concentrations of comparable compounds were approximately one to five times higher than found in this study for the San Pablo Bay site. Based on similar comparisons, the levels of PCBs and DDTs reported by Spies et al. (1985) were about 10 times and 100 times, respectively, the values found here. Spies et al. (1985) found that generally there were no major differences in the concentrations of the measured substances among the five open Bay sites that they examined (San Pablo Bay; near Richmond, Berkeley and Oakland; and, in the far south end of the Bay).

Measurements of sediment contaminants made in 1979 in Islais Waterway for some of the trace metals and PCBs by CH2M-Hill (1979) were generally similar to those found in the present study and also demonstrated a gradient of decreasing concentrations from the head of the waterway toward the mouth. No PAH measurements were made as part of the CH2M-Hill (1979) study. The reported DDT values were very variable but were roughly 10 times greater than found in the present study. However, the high level of spatial variability within Islais Waterway, which was indicated in both the CH2M-Hill (1979) and the present study, made direct comparisons between the two data sets difficult.

The reasons for the differences among the data presented in this study and those of CH2M-Hill (1979) and Spies et al. (1985) are unknown, but probably reflect in part the results of sampling different stations and sites, and using different sediment collection procedures (e.g., collecting sediments for analysis from the upper 2 cm sediment layer in the present study as opposed to the other two studies which analysed the 10-15 cm depth of sediment contained in a full Van Veen grab.

4.1.3 Comparisons with other West Coast areas

Sediment chemistry data for San Francisco Bay are compared to similar data from other areas of the West Coast in Table 15. These data were selected from available information for two areas that have been extensively sampled for comprehensive chemical analyses: the Southern California Bight and Puget Sound, Washington. Data for the concentrations observed in each case in sites away from urban influences (reference sites) and the maximum concentrations in surface sediments (upper few centimeters) were compiled for Table 15.

The data in Table 15 indicate that the concentrations of trace metals in the San Francisco Bay reference site may be slightly higher than those observed in reference sites off Southern California and in Puget Sound. This enrichment may reflect regional differences in the natural levels of the chemicals, the effects of grain size/TOC differences among the reference sites, and/or actual differences in the levels of anthropogenic contamination. Sufficient data were not available from all sites to allow comparison on a normalized basis to eliminate the confounding effects of grain size and TOC differences. However, the possibility of anthropogenic contamination is supported by indications (cf. Section 4.1.1) that the Bay may be fairly well mixed and hence partially contaminated at all sites. But, because the differences in the reference site values are not large and are not based on a large number of measurements, these conclusions can only be regarded as tentative.

Maximum concentrations of silver and chromium in Islais Waterway are 2-4X higher than the maxima in Puget Sound, but 7-8X lower than the maxima in the Southern California Bight. Levels of coprostanol were on the order of 50X higher at the San Francisco Bay reference site than at Puget Sound reference sites while maximum concentrations were similar for both areas; no comparable data were available for the Southern California Bight. Otherwise, the maximum concentrations for all of the other substances in Islais Waterway were much lower than the levels observed in contaminated sites in either Southern California or Puget Sound (Table 15). These data demonstrate the difficulty of using chemical data alone to define "problem areas." While the Islais Waterway site certainly stands out in the data set produced during this study as the most contaminated of the three sites in San Francisco Bay, none of the sites in the Bay were particularly enriched when compared to two other areas of the West Coast. Under this wider perspective, then, it would be difficult to say, given just the chemical data, that the San Francisco Bay data indicate that a problem (i.e., pollution-induced degradation) exists.

4.1.4 Chemical indices of pollution

The relative degree that the chemical concentrations in the sediments were elevated above the mean reference concentrations at the San Pablo Bay site was used as the criterion for selecting the chemicals most likely to be anthropogenically enriched and of concern. This Ratio-to-Reference (RTR) criterion was based on the

Table 15. Comparisons of the concentrations of chemical substances in the surface sediments of San Francisco Bay with data for two other West Coast areas

Substance	Concentrations, mg/dry kg					
	San Francisco[a]		So. Cal. Bight[b]		Puget Sound[c]	
	Ref. n=3	Max. n=1	Ref. n=4-28[d]	Max. n=1	Ref. n=5-28[d]	Max. n=1
Ag	1.2	8.6	0.2	4.6	1.2	2.4
As	56	72	ND[e]	ND	7.2	12,000
Cr	84	146	22	1200	54	62
Cu	44	130	8.3	1310	32	14,000
Hg	0.21	1.2	ND	ND	0.08	52
Ni	81	96	12	219	28	350
Pb	21	223	6.1	540	9.8	6,200
Sn	4.3	17	ND	ND	ND	ND
Zn	102	321	43	2720	62	4,200
LPAH	0.16	3.2	ND	ND	0.038-0.14	25.6
HPAH	0.58	12.1	ND	ND	0.13 -0.23	35.7
Coprostanol	0.48	31.5	ND	ND	<0.010	28.0
TDDT[f]	0.0007	0.004	0.007	220	<0.010	<0.010
TPCB[g]	0.011	0.26	0.004	11.0	0.002-0.012	2.0

a. Data from this study. Reference values are the mean of the concentrations at San Pablo Bay; maximum concentrations were observed in Islais Waterway.
b. Data from Heesen and Young (1977), Hershelman et al. (1977), and Jan and Hershelman (1980). Reference values are for 13 outer shelf sites, 60 m in depth. Maximum values are from a site adjacent to the Santa Monica sewage discharge except for Pb and Zn which are from a site adjacent to the Whites Point sewage discharge.
c. Data from Tetra Tech (1985). Reference values are the averages of data from seven nonurban areas of Puget Sound. Maximum values are from the surface sediments of Commencement Bay.
d. Some substances have been measured more frequently than others.
e. ND = No data available at present. Such data for the Southern California Bight have been collected by the California State Water Control Board, but were not available for inclusion in this report (J. Bowes, Calif. Water Control Board, personal communication).
f. TDDT = total DDT; DDTs have been detected in other Puget Sound sediments at low ng/g concentrations (Malins et al., 1980, 1982).
g. TPCB = total PCB

assumption that the reference site concentrations were among the lowest present in the Bay and that these concentrations were, in fact, indicative of reference or background conditions.

Using this criterion, lead, mercury, tin and silver are the trace metals that best indicated an anthropogenic affect among the three San Francisco Bay sites. Nearly all of the individual PAH compounds were substantially enriched for at least one site. However, rather than provide separate representations for each of these compounds, it was deemed appropriate to use the group sums of the LPAH and the HPAH to represent these compounds. The LPAH and HPAH compounds almost always occur as covariant groups of compounds, probably reflecting common source(s) (e.g., petroleum wastes for the LPAH and combustion products for the HPAH) (Curl, 1982). For the same reasons, the summed concentrations of DDT (including metabolites) and of total PCBs were considered the most appropriate representation of these compounds. In addition, although it is probably not toxic by itself, but because it derives primarily from mammalian digestive processes, coprostanol was included as an indicator of contamination.

The toxicity of the individual aromatic hydrocarbons and chlorinated organic compounds probably varies substantially. As a result, information regarding the potential impacts of these compounds, based on any a priori toxicity data, is lost when they are grouped in this manner. However, such groupings are appropriate for the present purpose of estimating the extent and level of differences in contamination at stations and sites.

The spatial distributions of these nine chemical indicators of anthropogenic enrichment (i.e., contamination) are depicted in Figures 26 and 27 as bar charts of the concentrations relative to the mean levels observed at the San Pablo Bay reference site. The data are presented on both a dry weight (Fig. 26) and TOC-normalized basis (Fig. 27). As expected, the indicator chemicals clearly identify the head of Islais Waterway as the site of greatest contamination and hence of greatest concern for possible biological impacts. Within the Islais Waterway site, when the data are normalized to dry weight, all of the compounds and particularly coprostanol were most enriched at the innermost stations (IS02 and IS05). In contrast, at the outermost station (IS09) all constituents were higher than but approached the concentrations seen at the other sites.

When the data are normalized to TOC (Fig. 27), the same trends are observed as for the dry weight normalized data, but all of the differences between stations are reduced. In particular, the range of concentrations in Islais Waterway is reduced and levels of Hg, Ag, Sn, the HPAH and DDTs (per unit measure of organic carbon) are actually higher at IS09 than at IS02.

The development of the ratios-to-reference concentrations of chemicals and the graphic portrayal of these ratios is a useful approach to readily identifying sites that have different chemical concentrations. When the ratios are used as a means of adjusting the scales of substances that occur over widely different concentration

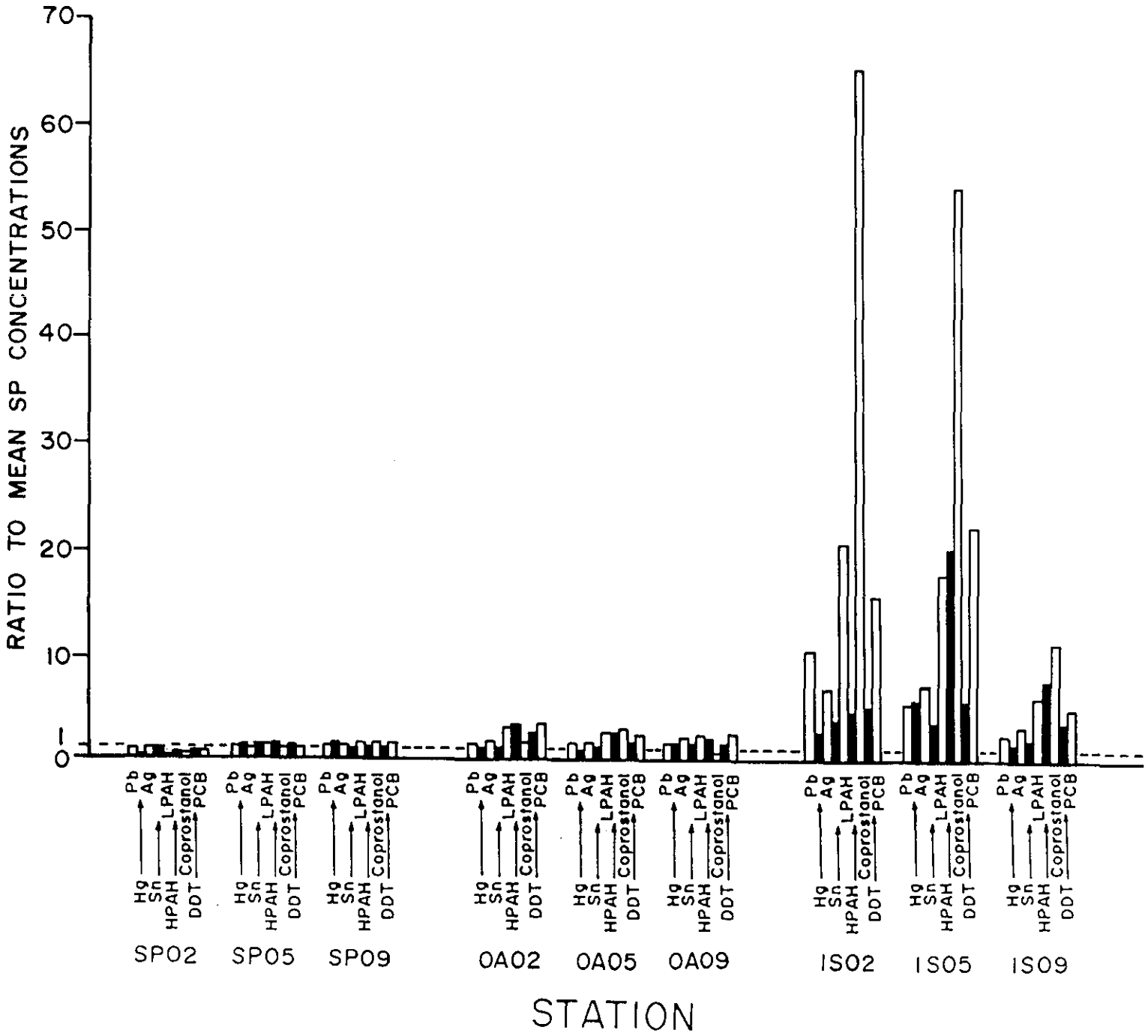


Figure 26. Ratios between dry weight-normalized mean reference site (SP) values and individual station values for nine chemical groups that appear to be anthropogenically enriched.

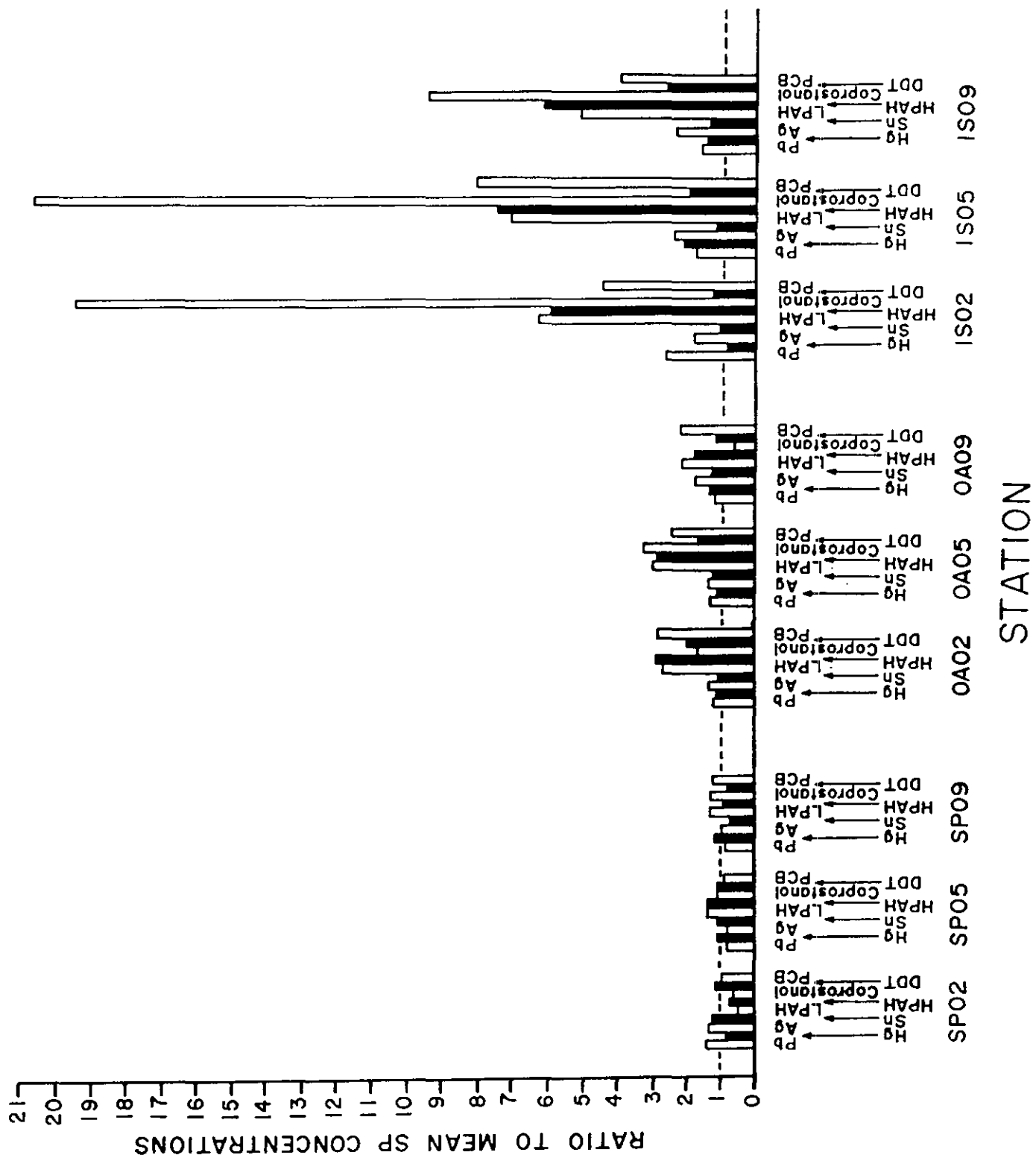


Figure 27. Ratios between TOC-normalized mean reference site (SP) values and individual station values for nine chemical groups that appear to be anthropogenically enriched

ranges, the selection of a particular reference site is not critical. Using chemical concentrations derived from a true "natural background" area, if such could be identified, would give a better measure of the extent of any anthropogenic enrichment. However, compounds such as PCBs and DDTs, which are totally anthropogenic, indicate anthropogenic enrichment if levels above true background levels of zero are measured. For these compounds, reference levels usually refer to the sites with the lowest observed concentrations.

When comparing two widely different areas, e.g., San Francisco Bay and Puget Sound, the same approach is valid as long as the data from both systems are normalized to the same reference values. The resulting indices would depict the relative concentrations of chemicals in each system and facilitate comparisons of the extent of contamination. Depending on the trends of most interest, a common reference site could be selected from either system alone or could be an average of data from both systems.

For more facile data comparisons with, for example, a multitude of other indices such as benthic infauna and sediment toxicity data, the resulting multiparameter chemical index can be reduced by combining the data from one or more substances or groups of substances as deemed appropriate. Such combinations might include, for example, single indices for all metals, for all aromatic hydrocarbons and for all chlorinated hydrocarbons. Alternatively all of the data could be combined to yield a single index value of chemical contamination. In order to maintain comparability among data from different sites where different chemical substances may have been measured, it is recommended that the combined indices (index) be calculated from the summation of the individual ratio-to-reference values divided by the number of substances included in the summation, and such data should be normalized to TOC or grain-size.

This combination approach renders comparisons between diverse data sets from many sites relatively straight-forward but, as with any index, there is a loss of information regarding which particular substances may be causing a high index value. The lost information may be important since the index values, as described herein, indicate the relative enrichment (elevations above the reference values) of the chemical substances and do not take into account any differences that may exist in the inherent toxicity of those substances. In the future it may be possible to provide toxicity weighting factors for specific chemicals or to actually develop indices based on the ratios of specific chemicals or combinations of chemicals to the toxicity threshold. However, such future developments must await more information regarding the toxic effects of chemicals in sediments.

Combining values may result in a "diluted" contamination index when only one or a few compounds are present at elevated concentrations, but many compounds are measured. An alternative that circumvents this problem, and still allows for facile comparisons among many stations and sites, is to select as the single index representative of a station or site the value of the compound(s) having the maximum RTR for that station (single measurement) or site (mean value).

The single compound maximum RTR approach is, in theory, not sensitive to differences in toxicity among the compounds selected, since the comparisons may be based on compounds of widely different toxicity. However, this is probably counterbalanced by the fact that very little suitable toxicity data are available to weight chemical concentration measurements and, in any case, the index value is simply an indication of the extent of anthropogenic contamination. Any toxicological inferences that can be gained are secondary.

Parameters to be included in the index are any that are known to be primarily enriched by human activities and that could result in degradation. At some sites even conventional parameters such as TOC or sulfide could fit this category. However, because natural organic enrichment can occur, such parameters are not recommended for inclusion in an index approach.

The data from San Francisco Bay were used to calculate various indices of contamination. Those chemical compounds that were consistently detected in the Bay and which are considered likely to be responsive to anthropogenic loading are summarized in Table 16 for dry weight-normalized data. This table includes all nine compounds that appear to be anthropogenically enriched in San Francisco Bay sediments, as previously discussed. Also included are the four additional elements (As, Cr, Cu, Zn) that were detected at all sites and that are considered to be highly responsive to anthropogenic loading. These data were used to generate three contamination indices using different methods. The first two methods involved combinations of the individual substance RTR values, the first by averaging all values listed (Aggregate Index 1), the second by averaging all of the trace elements to a single value prior to averaging this value with the individual values for the organic compounds (Aggregate Index 2). Thus, in the case of Aggregate Index 2, the final index value is the mean of combined values for five chemical groups and coprostanol. Both combined indices show the same trends of increasing index values from the San Pablo Bay site to the Oakland site to the Islais Waterway site. The differences between these two indices demonstrate the effects of altering the aggregating procedures, particularly the "dilution" of Aggregate Index 1 by the inclusion of individual elements in comparison to Aggregate Index 2, which combines the elements prior to averaging.

The third type of index, the maximum enrichment index, is also presented in Table 16. This latter type of index spanned a wider range of values than the combined indices.

Another consideration that needs to be dealt with in making these comparisons is the type of data normalization that should be used. The examples in Table 16 were based on the dry mass values and hence can be interpreted as indicating the relative exposure of a resident organism to contamination per unit mass of sediment. In contrast, comparisons based on TOC-normalized data (Table 17) provide information on the relative exposure of a resident organism to contamination per unit mass of organic carbon. As shown in previous data presentations, the TOC-based aggregate and maximum indices for San Francisco Bay show the same overall trends as the dry mass-

Table 16. Categorization of stations and sites based on dry mass-normalized sediment chemistry data. Values in dry weight divided by mean dry weight values for the San Pablo Bay reference site.

Site	Station	Ratio-to-Reference (RTR) Values													Aggregate Index 1[a]	Aggregate Index 2[b]	Maximum RTR Value	
		Ag	Cr	Cu	Pb	Hg	Ag	Sn	Zn	LPAH	HPAH	Coprostanol	DDTs	PCBs				
San Pablo Bay	02	0.79	0.86	0.68	0.84	0.42	0.75	0.70	0.84	0.20	0.39	0.34	0.65	0.50	0.61	0.47	0.86	(Cr)
	05	0.96	1.03	1.11	0.98	1.13	0.92	1.26	1.05	1.35	1.46	1.10	1.24	0.97	1.12	1.20	1.46	(HPAH)
	09	1.25	1.11	1.20	1.17	1.45	1.33	1.05	1.11	1.45	1.16	1.57	1.10	1.53	1.27	1.33	1.57	(Coprostanol)
	Mean	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.29	
	Std Dev	0.19	0.10	0.23	0.13	0.43	0.25	0.23	0.12	0.57	0.45	0.51	0.25	0.42	0.28	0.38	0.31	
Oakland	02	1.14	1.14	1.16	1.55	1.31	1.67	1.23	1.19	2.79	3.25	1.74	2.38	3.22	1.83	2.45	3.25	(HPAH)
	05	1.04	1.02	0.98	1.36	0.98	1.42	1.26	1.00	2.57	2.62	2.95	1.65	2.32	1.63	2.21	2.95	(Coprostanol)
	09	0.88	1.08	1.02	1.41	1.36	2.00	1.51	1.07	2.08	1.91	0.58	1.35	2.36	1.43	1.60	2.36	(PCBs)
	Mean	1.02	1.08	1.05	1.44	1.22	1.69	1.33	1.09	2.48	2.59	1.75	1.79	2.63	1.63	2.08	2.85	
	Std Dev	0.11	0.05	0.08	0.08	0.17	0.24	0.13	0.08	0.29	0.55	0.97	0.43	0.42	0.16	0.36	0.37	
Islais Waterway	02	1.02	1.60	2.95	10.45	2.67	6.75	3.95	3.14	20.38	20.74	65.63	4.55	15.73	12.27	21.85	65.63	(Coprostanol)
	05	1.18	1.75	2.23	5.39	5.63	7.17	3.49	2.20	17.79	20.33	54.31	5.60	22.33	11.49	20.66	54.31	(Coprostanol)
	09	1.29	1.31	1.55	2.30	1.73	3.33	1.86	1.52	5.94	7.70	11.34	3.48	5.01	3.72	5.89	11.34	(Coprostanol)
	Mean	1.16	1.55	2.24	6.05	3.34	5.75	3.10	2.29	14.70	16.26	43.76	4.54	14.36	9.16	16.13	43.76	
	Std Dev	0.11	0.18	0.57	3.36	1.66	1.72	0.90	0.66	6.29	6.05	23.39	0.86	7.13	3.86	7.26	23.39	

a. Assuming that all chemicals have equal weight, the individual RTR values for all 17 compounds are simply averaged for each station and site (n=17).
b. The mean RTR value for the 8 inorganic compounds is determined (n=8), then combined as a single measure with the five organic compound RTR values to provide an overall mean value (n=6).

Table 17. Categorization of stations and sites based on TOC-normalized sediment chemistry data. Values divided by mean values for the San Pablo Bay reference site.

Site	Station	Ratio-to-Reference (RTR) Values																
		As	Cr	Cu	Pb	Hg	Ag	Sn	Zn	LPAH	HPAH	Coprostanol	DDTs	PCBs	Aggregate Index 1[a]	Aggregate Index 2[b]	Maximum RTR Value	
San Pablo Bay	02	1.34	1.43	1.20	1.41	0.81	1.29	1.21	1.40	0.42	0.74	0.67	1.15	0.94	1.08	0.86	1.43	(Cr)
	05	0.79	0.82	0.94	0.79	1.04	0.76	1.04	0.84	1.35	1.34	1.05	1.05	0.88	0.98	1.09	1.35	(LPAH)
	09	0.87	0.76	0.87	0.80	1.15	0.95	0.75	0.76	1.23	0.92	1.28	0.80	1.18	0.95	1.05	1.28	(Coprostanol)
	Mean	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.35	
	Std Dev	0.24	0.30	0.14	0.29	0.14	0.22	0.19	0.28	0.42	0.25	0.25	0.15	0.13	0.06	0.10	0.06	
Oakland	02	0.89	0.86	0.93	1.18	1.16	1.32	0.98	0.91	2.65	2.86	1.58	1.92	2.78	1.54	2.14	2.86	(HPAH)
	05	0.96	0.92	0.93	1.24	1.03	1.33	1.19	0.91	2.91	2.75	3.20	1.58	2.39	1.64	2.32	3.20	(Coprostanol)
	09	0.72	0.86	0.87	1.14	1.27	1.67	1.27	0.86	2.09	1.78	0.56	1.15	2.15	1.26	1.47	2.15	(PCBs)
	Mean	0.86	0.88	0.91	1.18	1.15	1.44	1.14	0.89	2.55	2.46	1.78	1.55	2.44	1.48	1.97	2.74	
	Std Dev	0.10	0.03	0.03	0.04	0.09	0.16	0.12	0.02	0.34	0.49	1.09	0.31	0.26	0.16	0.37	0.44	
Islais Waterway	02	0.26	0.40	0.77	2.60	0.77	1.73	1.02	0.78	6.30	5.94	19.45	1.19	4.41	3.51	6.39	19.45	(Coprostanol)
	05	0.38	0.55	0.75	1.72	2.07	2.36	1.16	0.70	7.06	7.47	20.66	1.88	8.03	4.21	7.72	20.66	(Coprostanol)
	09	0.91	0.91	1.13	1.60	1.39	2.40	1.34	1.06	5.14	6.17	9.40	2.56	3.93	2.92	4.76	9.40	(Coprostanol)
	Mean	0.52	0.62	0.88	1.97	1.41	2.17	1.17	0.85	6.17	6.52	16.50	1.88	5.45	3.55	6.29	16.50	
	Std Dev	0.28	0.21	0.17	0.45	0.53	0.30	0.13	0.15	0.79	0.67	5.04	0.56	1.83	0.53	1.21	5.40	

a. Assuming that all chemicals have equal weight, the individual RTR values for all 17 compounds are simply averaged for each station and site (n=17).
b. The mean RTR value for the 8 inorganic compounds is determined (n=8), then combined as a single measure with the five organic compound RTR values to provide an overall mean value (n=6).

normalized data, but the differences among stations and sites are smaller and relative index rankings changed for some of the stations that had similar rankings based on dry mass normalization.

In using index values as a measure of contamination, it is preferable to use the normalized concentrations that best explain relationships between the concentrations of substances at the sampled locations. For this particular data set from San Francisco Bay, TOC and the percent silt were so linearly associated that use of either as a normalizing factor would yield comparable results. In most other areas, the sediment texture would probably show a more variable relationship with TOC, and either texture or TOC might be more clearly proportional to the concentrations of different chemical substances.

Because of these complications, and the complex judgements that could be required, because comparable measurements of TOC and grain size are often not available, and because normalization to parameters other than dry mass do not usually change the ranking of stations near background concentrations from those that are substantially contaminated, it may still be appropriate in studies where other normalizing data are not available, to compare locations primarily on the basis of dry mass values. If the data are available, however, normalization to TOC is preferable. In the future, as more and better chemical data become available, it is possible that other normalizations may be shown to be more appropriate.

The San Francisco Bay chemistry data may be somewhat anomalous in comparison with other areas in the extent to which all of the parameters covaried. Because of this covariance, and because of the relatively high chemical enrichment in Islais Waterway compared to the other sites, differentiating sites by chemical contamination was somewhat obvious. Even the conventional parameters (i.e., TOC, TVS, Eh, sulfides and percent silt) were as discriminating as many of the trace chemical substances. This uniformity in relative concentrations is not often the case. For example, many areas in Puget Sound show apparently random chemical distribution relationships, probably influenced by local inputs from unrelated sources (Quinlan et al., 1985; Tetra Tech, 1985). In these latter, probably more usual cases, the identification of contaminated sites can still be relatively straight-forward, but only if a sufficient suite of chemicals are analysed. Such identification of contaminated sites is accomplished through comparisons of ratios of the concentrations to reference conditions. The maximum RTR value approach may well be most useful in comparing data sets that have substantial differences in the types of substances measured. More realistic comparisons are obtained from combined indices, however, when comparable data for many substances are available. The latter is the case for San Francisco Bay.

In all cases, comparisons should be made initially on a dry mass basis and then with one or more appropriate alternative normalizations (i.e., TOC and/or sediment texture). The initial dry mass data probably provide better information regarding the relative levels of inputs and mass transfers among the sites, particularly for those near

active sources, but the alternative normalizations may well be a better overall indicator of potential degradation than the dry mass values.

A final, alternative, way of achieving a comparative ranking/scaling of the chemistry data is to subjectively scale the aggregate values, as discussed below. As previously noted (Table 15), the maximum levels of chemical contamination observed at the three sites in San Francisco Bay were generally much lower than those found in other contaminated marine areas of the West Coast. The concentrations of all chemicals measured at the San Pablo Bay site and at the Oakland site were somewhat higher or similar to the levels observed at sites considered representative of "background" concentrations in other studies (Tetra Tech, 1985; Heesen and Young, 1977). Both of these sites can thus be considered to be of low contamination based on the chemical parameters measured. Even the levels observed in the Islais Waterway site were at the low end of the range of maximum concentrations observed in areas of Puget Sound (Tetra Tech, 1985; Romberg et al., 1984) and the Southern California Bight (Heesen and Young, 1977; Herschelman et al., 1977; Jan and Herschelman, 1980).

Based on these comparisons, a subjective scale could be established that would reflect a reasonable segregation of sites by their levels of chemical contamination in sediments. Because of the lack of data for ancillary parameters and the lack of supporting toxicological evidence, these comparisons are based on dry mass values. Areas with low levels of contamination could be those where the ratio-to-reference concentrations of the indicator chemicals are no more than a factor of five higher (when the reference concentrations are near "background"). Moderate levels could range from factors of 5 to 50 times the reference concentrations, and highly contaminated areas could be those where the indicator chemicals exceed 50 times the reference levels. A number of localized sites in Puget Sound and Southern California have been found where the concentrations of one or more chemical substances exceeded the reference values by factors of 500 or more (e.g., Jan and Hershelman, 1980; Tetra Tech, 1985), indicating that the scale suggested here is conservative in designating areas as highly contaminated. In comparison, both the San Pablo Bay and Oakland sites were of low contamination, while the Islais Waterway site was of moderate contamination.

4.2 Toxicity Testing

The much higher maximum chemical concentrations observed in parts of the Southern California Bight and Puget Sound make the levels observed at the three sites in San Francisco Bay seem comparatively unimportant and bring us directly to the question of the significance of any particular concentrations of a chemical or suite of chemicals in sediments. The toxicity of a chemical substance in sediment may vary with its concentration and with the conditions encountered within a specific sediment, including texture, organic content, pH, Eh, and the form of the chemical. In addition, the analytical procedures available today do not measure all chemicals that may be toxic in a particular sediment sample. Sediment

chemistry data may, in at least some cases, only indicate the presence of a toxic substance that is not directly measured, as a result of its covariance in spatial distribution with another chemical that is measured. The measurement of sediment chemical concentrations can indicate areas of concern where potentially toxic impacts may be occurring, but cannot determine that toxicity, nor any consequent degradation (i.e., alteration of the resident biota by pollution). Sediment bioassays provide these necessary toxicity data.

4.2.1 Amphipod bioassay

The sediment bioassay with the amphipod Rhepoxynius abronius was used to determine acute lethality and a behavioral response. In the present study, only one sediment sample (10%) from the San Pablo Bay site and no sediment sample from the Oakland site showed significant acute lethality compared to the controls; no station at either of these sites showed significant sublethal (avoidance) effects compared to controls. In contrast, eight of ten stations (80%) in Islais Waterway showed significant lethality by this test, and four of ten (40%) showed significant sublethal (avoidance) responses. These results correspond with the observation of reduced abundance of amphipods at this site as compared to high abundances at the Oakland and San Pablo Bay sites. Thus this laboratory sediment bioassay produced data that could be related to ambient conditions.

The results of the sediment bioassay with amphipods showed that the Islais Waterway site sediments were highly toxic. The San Pablo Bay site, based on the amphipod sediment bioassay data, was slightly toxic compared to the Oakland site sediments, which were non-toxic. Extrapolating from these laboratory data to the possible effects on natural populations, we would predict that the Islais Waterway site would be highly degraded, while the San Pablo Bay sites would have a low level of degradation and the Oakland site would not be degraded.

4.2.2 Mussel larvae bioassay

The mussel larvae mortalities and abnormalities agreed with results of the amphipod test; they indicated that the sediments at the Islais Waterway site were highly toxic while those from the San Pablo Bay site were slightly toxic. In contrast to the amphipod bioassay results, however, the mussel larvae tests showed significant response to the sediments from the Oakland site. These results may indicate that the mussel larvae test is more sensitive than the amphipod test, or that the mussel larvae were responding to different components in the sediments than the amphipods. Extrapolating from these data, we would predict that degradation would be high at the Islais Waterway site, moderate off Oakland, and low in San Pablo Bay.

4.2.3 Clam reburial

The reburial response of Macoma balthica was used in the present study as a behavioral bioassay. Macoma is considered to be the single most important infaunal taxon in San Francisco Bay in terms of biomass (Nichols and Thompson, 1985), and M. balthica has

shown some evidence for abundance fluctuations related to trace metal contamination (Nichols, 1985). Two species of Macoma were found during the present study: M. nasuta and M. expansa. Macoma were not abundant in any of the samples; however, while similar low numbers were collected at the San Pablo Bay (4 individuals m2) and Oakland sites (3 individuals m2), substantially higher numbers were collected from Islais Waterway (11 individuals m2), all from IS09.

In the present study, slowest reburial times were observed in Islais Waterway sediments and fastest reburial times in San Pablo Bay sediments, with Oakland sediments being intermediate. However, because one of the five control replicates had an extremely slow reburial time (for unknown reasons), none of these differences were significant. If control data are excluded, then stations IS02, IS05 and OA09 had significantly (P=0.05) slower reburial rates than all other stations. Benthic collections at IS02 and IS05 did not include any Macoma, but two species (M. expansa and M. nasuta) were present at IS09. In contrast, Macoma (one species, M. expansa) were collected from OA09 but not from OA02 or OA05.

The bioassay data suggest overall that Islais Waterway was the most toxic site and Oakland was intermediate, with San Pablo Bay being the least toxic. However, these results provide only limited indications of the degree of degradation for several reasons. First, statistical significance has not been fully established due to problems with a control replicate. Second, the Islais Waterway site had 2-3X more Macoma among the infauna than either of the Oakland or San Pablo Bay sites. Third, Macoma were present at one of the three stations (OA09) that showed evidence for sublethal effects.

4.2.4 Harpacticoid copepod bioassay

The results of the harpacticoid copepod reproduction bioassays follow those of the other bioassay tests and indicate that Islais Waterway is the most toxic site. All Islais Waterway stations had significantly (P=0.05) lower reproduction rates than the controls.

However, in terms of separating out the two remaining sites, the results of this bioassay do not conform with those of the mussel larvae and clam reburial tests in which the Oakland site was more toxic than the San Pablo Bay site. Copepods exposed to San Pablo Bay sediments had significantly (P=0.05) lower reproduction rates than the control; in contrast, reproduction among copepods exposed to Oakland sediments was not significantly (P=0.05) different than the control. The results are somewhat similar to the amphipod bioassay, which determined San Pablo Bay sediments to be slightly toxic and those from Oakland to be non-toxic. Reproductive rates among copepods exposed to sediments at stations SP02 and SP09 were not significantly different (P=0.05) than those at the three Islais Waterway stations. On this basis, the Oakland site appears to be non-toxic while the San Pablo Bay site and Islais Waterway site are similarly toxic. This conclusion is supported by the fact that San Pablo Bay and Islais Waterway sediments both had lower mean survival of adult females relative to the controls and to the Oakland site sediments. If these results are extrapolated to determine the relative degree of

degradation at each site, we would predict that the site off Oakland was relatively non-degraded, while the San Pablo Bay and Islais Waterway sites were degraded to similar extents.

4.2.5 Combined result of all bioassay tests

Bioassay results are summarized in Figure 28. Of the four separate sediment bioassays and six separate measurements used to determine toxicity, the amphipod and mussel larvae bioassays (incorporating four separate measurements) both indicated that Islais Waterway was the most toxic site. The amphipod bioassay indicated that the San Pablo Bay site was slightly more toxic than the Oakland site however the bivalve larvae test indicated that San Pablo Bay was a relatively non-toxic site, and Oakland was a site with intermediate toxicity. The clam reburial bioassay indicated a pattern similar to that of the mussel larvae bioassay, and slowest clam reburial times at Islais Waterway stations IS02 and IS05 were associated with an absence of these clams (Macoma spp.) from the benthic infauna. The copepod reproduction bioassay indicated that the Islais Creek and San Pablo Bay sites were similarly toxic, while the Oakland site was relatively non-toxic.

The reason(s) for the difference between the results of the copepod and amphipod tests and the results of the other two bioassays is unknown, but may reflect a different sensitivity of crustaceans (amphipods and copepods) as compared to molluscs (clams) to particular chemical contaminants. It is also possible that the organisms are reacting to non-chemical factors such as sediment texture or Eh.

Unlike the sediment chemistry data, it is not possible to quantitatively compare the San Francisco Bay sediment bioassay data with similar data for other West Coast areas. Sediment bioassay data tend to be absolute, i.e., a sample either is or is not toxic by a particular test. Thus comparisons are best done in terms of relative percentages of toxic responses at a site (number of stations toxic divided by total number of stations tested). In Puget Sound, reference sites have shown between 0 and 32% significant lethal responses with the amphipod sediment bioassay while highly polluted sites have shown responses of up to 80% (Long, 1984, 1985). In the present study the amphipod bioassay gave between 0 and 10% lethal responses at the Oakland and San Pablo Bay sites, respectively, indicating that these sites have toxicity similar to Puget Sound reference sites. However, at the Islais Waterway site a total of 80% lethal responses (8 stations of 10 tested) were recorded, indicating that this site had similar toxicity to the most toxic Puget Sound sites.

In the previous sections, the toxicity data for each bioassay have been individually extrapolated to predict degree of degradation expected at each site. As noted above, the same relative rankings were not always obtained per station based on the individual bioassay data. A better method of determining relative toxicity to predict relative degree of degradation is to use the data from all the bioassays in a "preponderance of evidence" approach. There are two different ways of doing this, as detailed below.

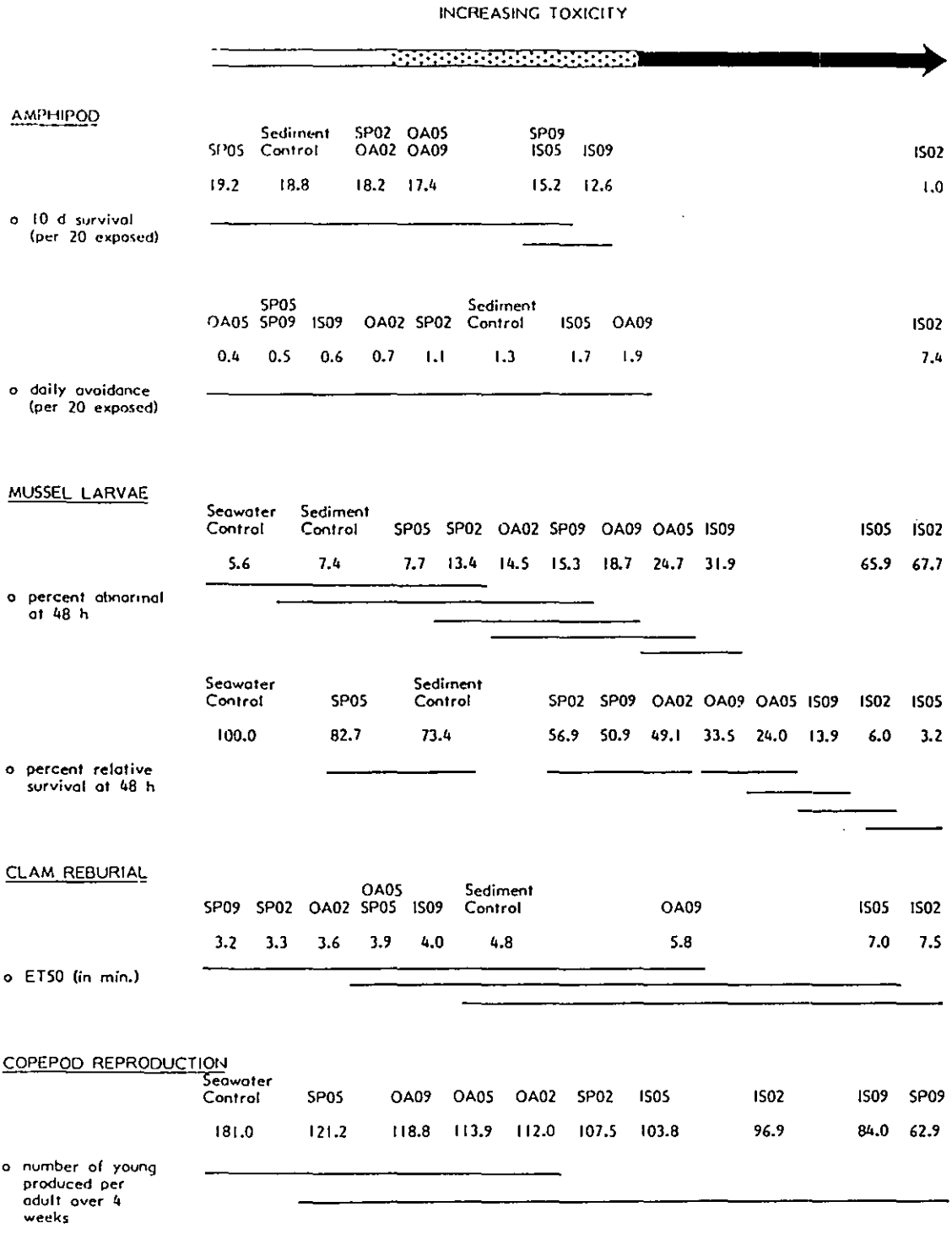


Figure 28. Summary of bioassay results (mean values). Treatments not underlined by the same line are significantly different at $P \leq 0.05$ (one-tailed t test).

The first approach to ranking stations and sites involves initially assuming that all of the sediment bioassay responses that are significantly (P=0.05) adverse compared to the controls have equal weight (i.e., assuming that the criteria for determining significant responses in each test are equal and appropriate). On this basis, a numerical scoring can be derived by giving each such response for each bioassay at each station an arbitrary value of unity. These scores are then summed for each station, added and averaged for each site to provide relative values for toxicity. This approach is used in Tables 18 and 19 for, respectively, all sediment bioassays, and only the amphipod bioassay (which was used at all 30 stations). Based on all bioassay tests (Table 18), Islais Waterway was the most toxic site, San Pablo Bay was the least toxic site, and Oakland had intermediate toxicity. In terms of individual stations, IS02 was the most toxic, while SP05 appeared to be non-toxic. Giving sublethal responses twice the weighting of lethal responses would have produced the same result. Extrapolating these results to relative degree of degradation would be expected to yield the same rank order. Using only the amphipod bioassay and data from all 30 stations (Table 19), Islais Waterway was even more clearly the most toxic site, and the San Pablo Bay site was slightly toxic compared to the non-toxic Oakland site.

A second way of treating the toxicity data is to use the San Pablo Bay site as a reference area, as was done for the chemistry and infauna data. By dividing numerical results for each bioassay measurement at each station by the mean values for the San Pablo Bay site, a dimensionless Ratio-to-Reference (RTR) value can be produced. This RTR value is a ratio of the response for each station or site compared to the mean for the reference site and may be greater than 1.0 (relatively toxic), equal or less than 1.0 (relatively non-toxic). RTR values are derived in Tables 20 and 21 for, respectively, all sediment bioassays at 9 stations and for only the amphipod bioassay at 30 stations. Using all bioassays, the Islais Waterway site was more toxic than Oakland, while Oakland was slightly more toxic than San Pablo Bay. IS02 was the most toxic station. Using only the amphipod bioassay (Table 21), the results were virtually the same except that IS01 now became the most toxic station. The same results would have been obtained if only combined data from the amphipod and mussel larvae bioassays were considered (cf. Fig. 28, Tables 20 and 21).

The data obtained in this study cannot be compared with other data for San Francisco Bay because no similar data sets exist. The only other sediment toxicity bioassay conducted to date in San Francisco Bay was a single R. abronius amphipod bioassay conducted recently (November 1985) at the Alcatraz dredged material disposal site near Alcatraz Island. This test resulted in a mean amphipod survival of 80%, which was significantly lower than control values of 93% (Enserco, 1986). Extensive bioaccumulation testing conducted to date in San Francisco Bay by the U.S. Army Corps of Engineers has used non-sensitive organisms, and bioassay data generated during these tests are not comparable to the sensitive sediment bioassays used in the present study.

Table 18. Summary of significant bioassay responsesa

Site	Station	Lethal	Sublethal	Sum	
SP	02	1	1	2)	
	05	0	0	0)	mean = 1.3
	09	0	2	2)	
OA	02	1	1	2)	
	05	1	1	2)	mean = 2.3
	09	1	2	3)	
IS	02	2	3	5)	
	05	1	2	3)	mean = 4.0
	09	2	2	4)	

a. Each significant bioassay response is given a value of unity.

Table 19. Categorization of sites based solely on amphipod bioassaysa

Siteb	Lethal	Sublethal	Sum
SP	1	0	1
OA	0	0	0
IS	8	4	12

a. Each significant bioassay response is given a value of unity.
b. Each site comprises 10 stations.

Table 20. Ratios between mean values for the reference site (SP) and individual station values for all sediment bioassays

Site	Station	Amphipod: Mean Mortality No. Dead	Amphipod: Mean Mortality RTR[a]	Amphipod: Mean Emergence No. Emerged	Amphipod: Mean Emergence RTR	Mussel Larvae: Mean Normality % Abnormal	Mussel Larvae: Mean Normality RTR	Mussel Larvae: Mean Mortality % Dead	Mussel Larvae: Mean Mortality RTR	Clam: ET50 (min)	Clam: RTR	Copepod: 200 minus # of young produced[b]	Copepod: RTR	Mean RTR Values[c]
SP	02	1.8	0.7	1.1	1.6	13.4	1.1	43.1	1.2	3.3	0.9	92.5	0.9	1.1
	05	0.8	0.3	0.5	0.7	7.7	0.6	17.3	0.5	3.9	1.1	78.8	0.8	0.7
	09	4.8	1.9	0.5	0.7	15.3	1.3	49.1	1.3	3.2	0.9	137.1	1.3	1.2
Overall	(n=3)[d]	2.5	1.0	0.7	1.0	12.1	1.0	36.5	1.0	3.5	1.0	102.8	1.0	1.0
OA	02	1.8	0.7	0.7	1.0	14.5	1.2	50.9	1.4	3.6	1.0	88.6	0.9	1.0
	05	2.6	1.0	0.4	0.6	24.7	2.0	76.0	2.1	3.9	1.1	86.1	0.8	1.3
	09	2.6	1.0	1.9	2.7	18.7	1.5	66.5	1.8	5.8	1.7	81.2	0.8	1.6
Overall	(n=3)	2.3	0.9	1.0	1.4	19.3	1.6	64.5	1.8	4.4	1.3	85.1	0.8	1.3
IS	02	19.0	7.6	7.4	10.6	67.7	5.6	94.0	2.6	7.5	2.1	103.1	1.0	4.9
	05	4.8	1.9	1.7	2.4	65.9	5.4	96.8	2.7	7.0	2.1	96.2	0.9	2.6
	09	7.4	3.0	0.6	0.9	31.9	2.6	86.1	2.4	4.0	1.1	116.0	1.1	1.8
Overall	(n=3)	10.4	4.2	3.2	4.6	55.2	4.6	92.3	2.5	6.2	1.8	104.7	1.0	3.1

a. RTR = Ratio-to-Reference
b. Arbitrary calculation used to adjust data for number of young produced per adult over 4 weeks in order to calculate RTR values in a similar format to other bioassay responses.
c. n = 6 separate toxicity values.
d. Mean reference site values used to determine RTR values. Note these are based on n=3.

Table 21. Ratios between mean values for the reference site (SP) and individual station values for sediment bioassays with amphipods

Site	Station	Mean Mortality No. dead	Mean Mortality RTRa	Mean Emergence No. emerged	Mean Emergence RTRa
SP Reference Site	01	2.4	0.8	0.5	0.8
	02	1.8	0.6	1.1	1.8
	03	2.6	0.9	0.8	1.3
	04	4.0	1.4	0.8	1.3
	05	0.8	0.3	0.5	0.8
	06	1.6	0.6	0.4	0.7
	07	3.2	1.1	0.4	0.7
	08	5.8	2.0	0.3	0.5
	09	4.8	1.7	0.5	0.8
	10	2.2	0.8	0.4	0.7
	Overall (n=10)[b]	2.9	1.0	0.6	1.0
OA	01	2.0	0.7	0.5	0.8
	02	1.8	0.6	0.7	1.2
	03	1.6	0.6	0.5	0.8
	04	4.0	1.4	0.6	1.0
	05	2.6	0.9	0.4	0.7
	06	4.0	1.4	1.1	1.8
	07	4.4	1.5	0.6	1.0
	08	2.4	0.8	0.8	1.3
	09	2.6	0.9	1.9	3.2
	10	2.2	0.8	0.4	0.7
	Overall (n=10)	2.8	1.0	0.8	1.3
IS	01	19.0	6.6	9.1	15.2
	02	19.0	6.6	7.4	12.3
	03	9.6	3.3	4.8	8.0
	04	20.0	6.9	7.0	11.7
	05	4.8	1.7	1.7	2.8
	06	4.2	1.4	0.4	0.7
	07	5.8	2.0	0.7	1.2
	08	6.2	2.1	2.7	4.5
	09	7.4	2.6	0.6	1.0
	10	10.0	3.4	0.2	0.3
	Overall (n=10)	10.6	3.7	3.5	5.8

a. RTR = Ratio-to-Reference.
b. Mean reference site values used to determine RTR values. Note these are based on n=10.

4.3 Benthic Infauna

4.3.1 San Francisco Bay infauna

The assemblage of marine infauna collected during this study was typical of soft-bottom benthic communities, dominated by polychaete annelids, and tube-dwelling amphipods. The taxa identified during this study were generally similar to those previously identified from San Francisco Bay, as discussed below.

Nichols (1979) reviewed benthic data collected at various depths and collected with variable methodologies at various sites in the Bay in 1973 and noted dominance by the following taxa: Heteromastus filiformis, Asychis elongata, Corophium spp., Neanthes succinea, and Mya arenaria. In the present study, H. filiformis was present but not dominant, while Asychis sp. (only juveniles were collected, making specific identifications uncertain) and Corophium sp. were both dominants. N. succinea and M. arenaria were not identified in the present study. Since these latter species are easily identifiable, their absence cannot be ascribed to differences in taxonomy. Thus these two species were either absent from the specific sites sampled in the present study, or were present at such low densities that they were not collected.

Nichols (1985) reported that the following species were dominant during a 10-year study of intertidal mudflats in South San Francisco Bay: Ampelisca abdita, Streblospio benedicti, Macoma balthica, and Gemma gemma. In the more northerly subtidal parts of San Francisco Bay sampled in the present study, A. abdita and S. benedicti were dominants, as were Macoma nasuta and Macoma expansa. Neither M. balthica nor G. gemma were identified in this study, suggesting that these species are absent or only present in low densities in the subtidal sites sampled.

The only previous study to identify oligochaetes in San Francisco Bay was conducted by Brinkhurst and Simmons (1968) using samples collected throughout the Bay with variable methodologies in 1961-1962. The only geographical site of overlap with the present study was San Pablo Bay. These authors identified four species: Peloscolex gabriellae, P. apectinatus, P. nerthoides and Paranais frici. None of these species were identified in the present study, which is not surprising for two major reasons. First, the 1.0 mm sieve used in the present study prevented any but the most incidental collection of these small meiofauna. Second, species descriptions have radically changed in the almost 20 years since Brinkhurst and Simmons (1968) conducted their study. The genus Peloscolex no longer exists; many of the species in this genus have been reassigned to the genus Tubificoides (Brinkhurst and Baker, 1979). And, in fact, two species of Tubificoides (T. wasselli and T. brownae) were collected in the present study from the San Pablo Bay site. The third species of oligochaete, Limnodriloides victoriensis, collected only from Islais Waterway, represents a new distribution record for this species, which had not previously been reported south of the Pacific Northwest (Dr. R. Brinkhurst, IOS, Canada, pers. comm.).

CH2M-Hill (1979) conducted a benthic survey off the east shore of the city of San Francisco, with two stations in Islais Waterway. Methodologies (depth, sampler, screen size) were similar to the present study. As in the present study, they found the head of Islais Waterway (their Station 12) to be depauperate; this station contained 11 taxa, but six of these were freshwater species that appeared to have been recently washed out of adjacent combined sewer overflows (CSOs). Abundant taxa common to both the CH2M-Hill (1979) and present studies include: Glycinde sp. (identified as G. picta by CH2M-Hill (1979)), Capitella capitata, Streblospio benedicti, Ampelisca milleri (= A. abdita; Dr. F. Nichols, USGS, Palo Alto, pers. comm.), Macoma nasuta and Transenella tantilla. Two species that were abundant in the CH2M-Hill (1979) study, but which were not collected in the present study, Cirratulus cirratus and Cirriformia spirabranchia, may have decreased in abundance between the two studies.

4.3.2 Comparisons with data from other areas

A total of 70 benthic infaunal taxa were identified from 45 grab samples taken at fifteen stations and three sites in San Francisco Bay. At any one station taxa richness ranged from 5 to a maximum of 35 taxa. Taxa richness at any one site ranged from 20 to a maximum of 43 taxa. Each site was dominated by one of two taxa, Ampelisca abdita or Capitella capitata.

The presence of a limited number of taxa and dominance by an individual taxon is one characteristic of organically enriched (i.e., degraded) or disturbed subtidal soft-bottom areas (Pearson and Rosenberg, 1978). If we had had only the benthic infaunal data available for evaluation, all three sites in San Francisco Bay would have appeared to have been degraded (i.e., comprising resident biota altered by pollution) in comparison with other West Coast areas.

Although methodologies (e.g., number of samples) and sites (e.g., depth) were not exactly comparable with the present study, the following examples provide information on faunal numbers collected in other studies from other West Coast areas. In Puget Sound, Stober and Chew (1984) recorded means of between 109 and 128 taxa at 15 to 60 m depths in reference sites outside of the urban embayments. Broad et al. (1985) recorded a total of 172 subtidal taxa in Bellingham and Samish Bays, Puget Sound. Also in Puget Sound, Chapman et al. (1985a) recorded a total of 193 taxa from various sites, at depths of between 7 and 60 m. Swartz et al. (1985b) collected a total of 319 taxa from seven stations on the 60 m depth contour of the Palos Verdes Shelf in the Southern California Bight.

One study that is more directly comparable with the present study was recently (1985) conducted in Hecate Strait, B.C. (E.V.S. Consultants, unpublished data). Methodologies were identical to the present study (three sites, three stations per site, five replicates per station, 0.1 m2 Van Veen grab, 1 mm sieve, same sorters, same taxonomists) and involved sampling at comparable depths. A total of 250 taxa were collected from Hecate Strait as compared to 70 from San Francisco Bay.

These differences between the San Francisco Bay benthos and other West Coast benthic communities may, at one extreme, be due to widespread organic pollution in the Bay. At the other extreme, San Francisco Bay infaunal communities may be naturally depauperate due to a high sedimentation rate which encourages opportunistic species and limits diversity. In either case, the lack of a more obviously "natural" benthic community in at least the reference site, San Pablo Bay, makes it difficult to use the benthic data alone to determine whether or not anthropogenic activities are factors governing the observed species distributions.

4.3.3 Biotic indices of pollution

The following parameters were used as indices to summarize the benthic infaunal data, and each is evaluated for possible use with the Triad:

- Taxa richness
- Total abundance
- Relative abundance of major taxa
- Numerical dominance
- Diversity
- Log-normal distribution
- Similarity to reference (cluster analysis).

Taxa richness (number of taxa) and total abundance (number of individuals) are commonly reported variables, and have been used extensively to evaluate pollution effects (cf. Pearson and Rosenberg, 1978). Pristine sites typically have high taxa richness and total abundance. Power analyses have shown that taxa richness is a precise measure of community change relative to other benthic variables (Tetra Tech, 1985). Significant statistical differences can be detected using as few as two 0.01 m^2 Van Veen grabs, making taxa richness an efficient tool with which to evaluate community responses to pollution. Total abundance generally exhibits more within-station variability than does taxa richness, and is therefore a relatively less powerful statistical measure. But changes in total abundances do occur in response to pollutant stresses (cf. Pearson and Rosenberg, 1978) and can be tested statistically.

The relative abundance of major taxa was included to facilitate the identification of problem sites. This analysis assessed major taxonomic groups considered to be sensitive to pollution (e.g., amphipods) and those considered more tolerant (e.g., polychaetes and molluscs). Amphipods are among the infaunal groups most sensitive to environmental degradation (Bellan-Santini, 1980). Chapman et al. (1985a) and Long and Chapman (1985) have shown a correspondence between depressed amphipod abundances, elevated polychaete and mollusc abundances, and sediment toxicity on a site-site basis, but not necessarily on a station-station basis.

Dominance was calculated as the complement of equitabilty. This index provides useful information on the dispersion of individuals among the species in a benthic community.

On the basis of the above first four parameters, Islais Waterway was the most degraded site. It was the most depauperate, in terms of taxa richness and total abundance, of the three sites sampled. The fauna were dominated by polychaete annelids, and amphipods were rare. However, within-site variability was high, with station IS09 differing greatly from IS02 and IS05. Stations IS02 and IS05 had 45-60 individuals distributed over 2-3 taxa, however station IS09 had fewer individuals and four times the number of taxa. IS09 was the only station in Islais Waterway that did not include the "indicator" polychaete Capitella capitata. These differences between the infauna at station IS09 as compared to the other two Islais Waterway stations may be due to a number of factors including grain size differences in the sediments. They could also be due to a lower level of organic enrichment at IS09.

The reference site, San Pablo Bay, had a mean of ten taxa, with an average of 600 individuals in each grab sample (0.1 m2). Dominance was high at this site due to the presence of the tube-dwelling amphipod Ampelisca abdita, which contributed over 90% of the total number of individuals. A few species of polychaetes were found in this site, while molluscs were virtually absent.

The Oakland site had a mean of 14 taxa, with an average of 3,500 individuals in each grab sample. But this site also had the highest degree of numerical dominance of the three sites sampled. The tube-dwelling amphipod A. abdita was again dominant. Although this amphipod species is being used in sediment bioassays on the East Coast as described below, in Norwegian fjords Ampelisca spp. have been classified as generally "very tolerant" to pollution (Rygg, 1985). The fauna are dominated by deposit and/or suspension feeders, and exhibit an increased abundance of "opportunistic" taxa in conjunction with a decrease of other taxa representing a wide range of functional groups (e.g., sediment processors, carnivores). The reference site, San Pablo Bay, was similar in taxon composition. This type of taxon distribution is considered indicative of organic pollution (Pearson and Rosenberg, 1978).

Two taxa were dominant components of the benthic infauna in San Francisco Bay: the polychaete Capitella capitata at the Islais Waterway site, and the amphipod Ampelisca abdita at the Oakland and San Pablo Bay sites. C. capitata is a pollution-tolerant species whose dominance in an area is considered to be indicative of degradation associated with organic pollution (Reish, 1955, 1980; Pearson and Rosenberg, 1978). A. abdita is presently being used by the U.S. EPA (Narragansett Laboratories) in solid phase toxicity testing, using techniques similar to those developed by Swartz et al. (1985a) for the Rhepoxynius abronius sediment bioassay used in the present study (Gentile et al., 1985). A. abdita is apparently somewhat less sensitive than R. abronius, and is commonly found in fine sediments such as those sampled in San Francisco Bay (K. Scott, U.S. EPA Naragansett Laboratories, pers. comm.; R. Swartz, U.S. EPA Newport Laboratories, pers. comm.). C. capitata was not found at the Oakland and San Pablo Bay sites, while A. abdita was rare at the Islais Waterway site.

Simply on the basis of these species distributions, the Islais Waterway site could be considered organically degraded in comparison with the other two sites.

Diversity was also used as an index to analyse the benthic infauna data. Diversity indices have a number of problems associated with their use. These have been thoroughly discussed by Washington (1984) and will not be reiterated here. Since measures of diversity are ubiquitous in benthic infaunal studies, this parameter was used for comparative purposes in the data analyses. However, not unexpectedly, this index did not provide useful data analyses and, in fact, provided misleading results. A major problem encountered with using the diversity index in the present study followed that discussed by Birch (1981), specifically that in many soft-bottom marine environments dominance increases with a corresponding increase in taxa richness. Since diversity is based on the opposite assumption, high diversity is associated with low dominance (i.e., high equitability). For example, station IS09 had a diversity of 0.83, much higher than the diversity of 0.17 recorded at OA09. These results suggest that IS09 was over four times as diverse as OA09, and hence apparently less stressed. However, in fact, the reverse was true. Station IS09 had a mean species richness of 8.2, with a dominance of only 0.08 (high equitability). Station 0A09 had a mean species richness over twice as high as IS09 (16.6), but a dominance of 0.85 (very low equitability). Thus the diversity values, influenced by dominance, show IS09 as having the highest diversity. Because of station IS09, the Islais Waterway site had the highest overall diversity, the San Pablo Bay site had intermediate diversity, and the Oakland site had the lowest diversity (by this index measure). Because extreme abundance values obscured differences in actual numbers of taxa in this particular diversity estimation, these index values were excluded from further consideration.

Another method used to describe and differentiate sites based on the benthic infauna involved determining their log-normal distribution. Determination of the log-normal distribution of individuals among the taxa present at any one site has been shown to be useful in illustrating possible deviations from a "natural" state (Gray and Mirza, 1979; Gray, 1981). In most unpolluted situations the distribution of individuals among species is characterized by numerous incidental taxa, with a few moderately abundant taxa, and only one or two taxa which are very abundant (but not highly dominant). Such data plotted as the cumulative number of taxa (as a percentage of the total taxa, on a probit scale) against the geometric class of the numbers of individuals per taxa, would yield a steep, linear relationship. In a stressed environment this distribution will change. In some cases incidental, or rare taxa will be eliminated due to a toxic response, and other taxa may become extreme dominants as a result of reduced competitive pressures and/or organic enrichment. The resultant log-normal plot is no longer wholly linear for recent disturbances, and is typically disrupted by a break in the middle and expansion over a greater number of geometric classes (incorporating the dominant, opportunistic species). Long-term disturbances may be characterized by a shallow, linear relationship spanning a greater number of geometric classes than the "natural" state.

The results of the log-normal analyses indicated that all three sites sampled in San Francisco Bay were altered from "natural" conditions, which is in accord with the data as previously discussed. However, this result may also be a reflection of an inherent inadequacy of this type of analysis. The log-normal method is well suited to most marine communities, particularly those in sand or cobble environments, provided that the basic assumption of a large, heterogeneous sample size (i.e., containing representative proportions of all resident taxa) is maintained. Recently Gray (1985) has suggested that data for marine soft-bottom communities may not fit the log-normal distribution under all "natural" conditions. This lack of "fit" has been suggested to occur as a result of multiple log-normal distributions over the span of geometric classes; that is, a linear relationship exists over the incidental taxa, but a slightly different one exists over the moderately abundant taxa, and the very abundant taxa. This theory remains to be fully explored (Gray, 1985), but it is worth noting that the San Pablo Bay site data (Fig. 25) seem to have three separate linear relationships over the 13 geometric classes spanned. On this basis, the San Pablo Bay site could be considered the most "natural" area. The data for the Oakland and Islais Waterway sites both have sharp breaks in the log-normal plot indicative of recent disturbance, however Oakland has the highest number of geometric classes and would thus be considered more disturbed than Islais Waterway. However, since the adequacy of using the log-normal distribution for marine soft-bottom communities is in doubt (Gray, 1985), because the results do not fit those originally described by Gray and Mirza (1979), and because the applicability of the log-normal distribution to toxic chemical effects as opposed to organic pollution is uncertain (Rygg, 1986), these analyses were excluded from further consideration.

The above array of techniques used for analysing the benthic infaunal data involved univariate or bivariate indices. A further, multivariate analysis (e.g., employing a clustering technique) is essential in interpreting benthic infauna data as multivariate techniques extend the concept of single sample analyses (i.e., those analyses that are performed on single samples and then compared between samples) to the level of simultaneous between-station comparisons. Cluster analysis is only one such method. Other methods which, though not used here could be equally useful include: Principal Components Analysis, Detrended Correspondence Analysis, Factor Analysis and MANOVA. The results of a cluster analysis supported the results of the majority of the univariate and bivariate indices. Oakland and San Pablo Bay stations were relatively similar, while Islais Waterway stations were dissimilar from the other two sites. Within each site, Oakland and San Pablo Bay showed a high level of similarity for the three stations sampled in each site. Station IS09 was dissimilar from the other two Islais Waterway stations, and from all other stations.

In addition to pollution, biotic factors (e.g., competition, predation) can influence benthic infaunal community structure. These factors become important considerations when sediment parameters are considered along with the benthic infaunal data. As previously mentioned, if only the benthic infaunal data were considered, organic pollution is suspected. However, TOC and TVS data for these two

sites are within the normal estuarine range of values and do not suggest a high level of organic enrichment. It is possible that competitive exclusion by Ampelisca abdita at the Oakland and San Pablo Bay sites served to limit diversity, resulting in a dominated faunal assemblage indicative of some forms of organic pollution, but not necessarily a result of this condition. Dominance of the benthic infauna by tube-building A. abdita results in changes to the sediments including decreased median grain size, and can also result in an overall decreased species richness (Mills, 1969). A. abdita may be responding opportunistically to particular conditions in San Francisco Bay (e.g., high clay, marginal organic matter, high currents).

Two major physical factors can also greatly influence benthic infaunal community structure: sediment grain size and depth (Nichols, 1979). Every effort was made to collect the same type of sediment from the same depth at each sampling station. However, although water depths were kept relatively constant (6-12 m), there were some differences in grain size distributions. The San Pablo Bay sediments consisted, on average, of almost equal measures of sand, silt and clay. In comparison, Oakland sediments had substantially less sand and more clay; Islais Waterway sediments were predominantly silt. As previously discussed, Islais Waterway benthic fauna differed from those of the other two sites. Oakland and San Pablo Bay also differed from each other, but were much more similar than to Islais Waterway benthic fauna. These levels of faunal differences approximate the levels of grain size differences between the sites, and may in themselves account for the observed faunal differences between the sites, irrespective of sediment chemical contaminants.

The use of different parameters/methodologies is an important aspect to assessment of benthic infaunal community structure, particularly in obtaining reliable information for subsequent comparison with sediment chemistry and toxicity data. Use of multiple methodologies will act to confirm trends and eliminate problems associated with some methods and not with others. The following four parameters proved, as discussed above, appropriate individual indices to summarize the benthic infaunal data and to objectively provide a numerical index capable of differentiating between the stations and sites:

- Taxa richness
- Total abundance
- Relative abundance of major taxa
- Numerical dominance.

These parameters are used in Table 22 to obtain a categorization of sites relative to the reference site, San Pablo Bay. Comparison of community descriptive parameters as a combined measure was evaluated using the assumption of equitability between each parameter's ability to describe a particular aspect of community structure. Hence, results were considered additive (with no weighting factors included), and served to provide an average numerical "description" of site conditions relative to a given reference (the San Pablo Bay site). On this basis, the benthos at the Islais Waterway

Table 22. Relative categorization of sites based on benthic infauna data

Analysis/Parameter	Ratio to Reference[a] San Pablo Bay	Oakland	Islais Waterway
1/Taxa Richness[b]	1.0	0.71	4.76
1/Total Abundance[b]	1.0	0.17	11.11
Numerical Dominance	1.0	1.14	0.83
1/% Amphipoda[b]	1.0	0.96	33.33
% Polychaeta	1.0	0.28	14.29
% Mollusca	1.0	0.58	84.75
Sum:	6.0	3.84	149.07
Mean[c]:	1.0	0.64	24.85

a. Reference = mean San Pablo Bay site values.
b. High values = least altered, thus these data are entered as reciprocals.
c. Relative degree of alteration compared to mean reference values. Values greater than 1.0 indicate greater alteration, values less than 1.0 indicate less alteration.

site were almost 25X more altered than those at the San Pablo Bay site, while the benthos at the Oakland site were slightly less altered than those at the San Pablo Bay site.

The same approach is used in Table 23 to differentiate stations. All Oakland stations were slightly less altered from background conditions than the San Pablo Bay stations. All Islais Waterway stations were more altered. Station IS09 had the highest mean value (54X reference), due to the high percentage of Mollusca found at this station compared to the reference.

This relative categorization provides useful information for comparing sites and stations but provides no information for determining degree of pollution-induced degradation for the infauna relative to other West Coast areas. Based on previously discussed comparisons with other West Coast areas, a subjective prediction of pollution-induced degradation can be established as follows. The Oakland and San Pablo Bay sites and all stations in these sites had a relatively low taxa richness (mean 10-14) and a high dominance by one species. Thus although there are slight differences between the two sites, they can be considered to be moderately degraded (altered infaunal community structure suggests pollution), based on the benthic infaunal data alone. Islais Waterway stations IS02 and IS05 had very low taxa richness (mean 2-3) and a high dominance by one species, the pollution "indicator" Capitella capitata. Thus these stations can be considered to be highly degraded. Station IS09 had more taxa than the other two Islais Waterway stations but less than the Oakland and San Pablo Bay stations, no Capitella capitata, and no one taxon was dominant at this station. IS09 is considered to be highly degraded due largely to the low proportion of amphipods and extremely high proportion of molluscs present. In the following section, these predictions of the degree of degradation based on the infauna are compared with the sediment chemistry and bioassay data.

4.4 Sediment Quality Triad

4.4.1 Determination of the Sediment Quality Triad in San Francisco Bay

Pollution is defined as a biologically damaging excess of contamination. There is a sharp and clear distinction between contamination (the presence of concentrations of a substance above the natural background levels in sediments) and pollution-induced degradation (involving a threat to human life, harm to living resources, or some other deleterious effect). The Sediment Quality Triad includes sediment chemistry measurements to determine contamination, and includes bioassay and infauna measurements such that biological indicators of pollution-induced degradation can be assessed at specific stations and sites. This approach is named for the three components of the Triad, as illustrated in Figure 29. The relative information provided by each component of the Triad related to an absolute measure of pollution-induced degradation is summarized below:

Table 23. Relative categorization of stations based on benthic infauna data

Analysis/Parameter	Ratio to Reference[a] San Pablo Bay 02	05	09	Oakland 02	05	09	Islais Waterway 02	05	09
1/Taxa Richness[b]	1.56	1.05	0.71	0.81	0.78	0.62	4.35	5.26	1.25
1/Total Abundance[b]	0.95	1.64	0.75	0.20	0.16	0.16	12.50	10.00	50.00
Numerical Dominance	0.90	0.99	1.10	1.16	1.12	1.12	0.81	0.84	0.10
1/% Amphipod[b]	1.00	1.03	0.97	0.95	0.97	0.95	2.63	5.88	10.53
% Polychaeta	1.04	1.22	0.74	0.35	0.26	0.23	14.29	14.29	8.33
% Mollusca	0.67	2.00	0.33	0.00	1.00	0.83	0.00	0.00	254.33
Sum:	6.12	7.93	4.6	3.47	4.29	3.91	34.58	36.27	324.54
Mean[c]:	1.02	1.32	0.77	0.58	0.71	0.65	5.76	6.04	54.09

a. Reference = mean San Pablo Bay site values.
b. High values = least altered, thus these data are entered as reciprocals.
c. Relative degree of alteration compared to mean reference values. Values greater than 1.0 indicate greater alteration, values less than 1.0 indicate less alteration.

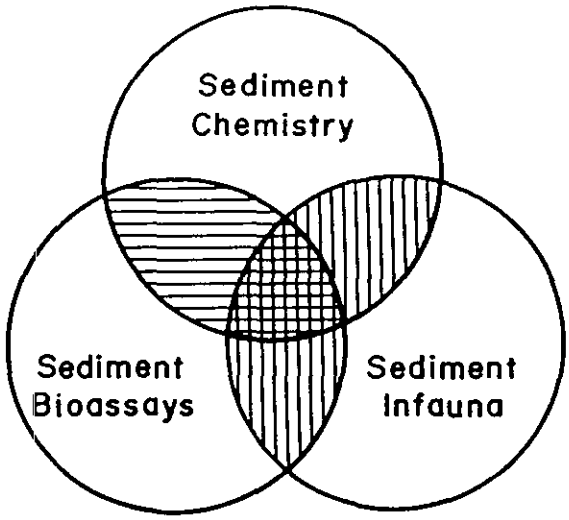
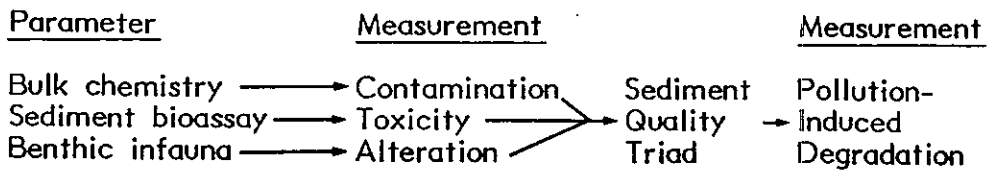


Figure 29. The three components of the Sediment Quality Triad used in the present study. The component represented by Sediment Infauna provides a measure of *in situ* effects related to station-specific sediment contamination. If other measures such as resident organism histopathology, which do not involve relatively sessile benthic organisms, are used to represent this component of the Triad, the data can no longer be applied on a station-specific basis but may be usable on an area-specific basis. Geographic stations, sites or areas where the three components of the Triad show the greatest overlap (in terms of either positive or negative results) provide the strongest data for assessing pollution-induced degradation. The strength of the Triad, however, lies in the use of these three measures to address pollution-induced degradation where the data do not overlap.



The difficulty in most pollution investigations lies in obtaining information that will clearly identify those sites where actual (biological) harm to the receiving environment has been done or is occurring due to contamination. Bulk chemical analyses measure contamination and cannot be used by themselves to determine pollution, as illustrated by the data obtained in this study for San Francisco Bay. By themselves, the Islais Waterway sediment chemistry data, although the highest of any measured in this study, might not seem of major concern compared to the much higher maximum levels measured by others in other contaminated areas of the West Coast (e.g., Puget Sound, the Southern California Bight).

However, the level of concern goes up markedly when the bioassay data are included, because the bioassay results (which are performed in worst-case conditions in a laboratory) leave no doubt that the sediments from the Islais Waterway site are toxic and pose an obvious threat to the receiving system. Even these data may be discounted, however, as overestimating "real world" impacts or using inappropriate organisms that do not actually live in the affected areas, or having end-points that are not indicative of in situ effects. A final piece of evidence is therefore required, in this case the benthic community data. The benthic community data clearly showed that the benthic infauna at the Islais Waterway site in particular (where the highest levels of contamination and toxicity were recorded) were substantially altered from what would be expected in a "natural" community.

The benthic data from San Francisco Bay provided necessary information to the Triad, but they also provided a good example of why benthic data alone cannot be used to determine pollution-induced degradation. All of the sites sampled, including the reference site, had benthic communities that were markedly different than those observed in similar substrates in other West Coast areas. These differences could be interpreted to reflect a normal response to the particular habitats in the Bay, or Bay-wide pollution impacts, but without sediment chemistry and bioassay data the significance of this alteration in the benthos, discussed below, could not be determined. The importance of the Triad in this regard is emphasized when considering comments by previous investigators concerning use of the San Francisco Bay benthos for determining pollution. Nichols (1979, 1985) noted that natural perturbations easily mask possible anthropogenic effects. Nichols and Thompson (1985) could not, in ten years of observation of a mudflat community in the Bay, differentiate other than catastrophic pollution events from natural variation.

The initial hypothesis of this study was that the Sediment Quality Triad is necessary to determine pollution-induced degradation and that no individual component of the Triad alone provides the data necessary for this assessment. To initially test this hypothesis and

the Triad approach in San Francisco Bay, each individual Triad component was used separately to predict relative degree of degradation. These predictions, which were made independently, and which have been previously discussed, are summarized in Table 24. In no case was there 100% agreement in the relative rankings of the separate components of the Triad, and there was one case where there was 0% agreement. Also there were no cases where all three measures agreed that Islais Waterway was degraded. Thus this initial test indicates that our hypothesis concerning the necessity of using the Sediment Quality Triad to measure pollution-induced degradation is correct as no individual Triad component could be used consistently to predict the behavior of the other two Triad components. A determination of which particular components agree allows determination and prioritization of sites and stations based on level of pollution-induced degradation.

Five stations (SP02, SP05, SP09, OA02, OA05) were the least pollution-degraded. Although the infauna were modified at these stations (compared to other West Coast areas), the lack of elevated chemistry and low toxicity in the bioassay tests indicated that this was not a result of chemicals that were measured.

Two stations (SP09, IS09) were slightly pollution-degraded. Although sediment chemistry levels were low, the infauna were modified (highly modified in the case of IS09) and there was moderate sediment toxicity. These data indicated that changes observed in the infauna may have been at least partly due to pollution, and that these stations were therefore slightly impacted.

The remaining two stations (IS02, IS05) were the most pollution-degraded. The infauna showed a high level of modification, and sediment chemistry levels were moderate. At Station IS02 bioassay responses were highly elevated, indicating that this station was of more concern than IS05, where bioassay responses were only moderately elevated.

Although there were substantial grain size differences between the innermost Islais Waterway stations (IS02, IS05) and all other stations, the Triad provided evidence to separate pollution-induced degradation from possible grain size effects. Continued application of the Triad approach in a variety of sites should lead to better refinements of the importance of the different components. For example, some preliminary data have recently become available from studies performed in contaminated areas of Puget Sound, Washington, regarding the concentrations of specific chemicals in sediments that co-occurred with toxicity (Tetra Tech, 1985; Chapman, in press a). These data were developed from synoptic area-wide measurements of toxicity (bioassays), benthic community impacts or bottomfish liver lesions, and chemical/physical characterizations. Because sites where single-chemical effects could be distinguished were limited, only a few of the potentially toxic substances could be fully analysed. The results of these studies were expressed as the "apparent effect threshold," the concentration in the sediment samples above which the sediments were always toxic in laboratory bioassays or in which the infauna were altered relative to reference conditions. The apparent

Table 24. Summary of subjective indices of relative degrees of "degradation" predicted for each individual component of the Sediment Quality Triad*

Site	Station	Predicted Degradation			Percent Relative Agreementd
		Chemistrya	Bioassayb	Infaunac	
SP	02	L	L	M	67%
	05	L	L	M	67%
	09	L	L	M	67%
	Overall (n=3)	L	L	M	67%
OA	02	L	L	M	67%
	05	L	L	M	67%
	09	L	M	M	67%
	Overall (n=3)	L	M	M	67%
IS	02	M	H	H	67%
	05	M	M	H	67%
	09	L	M	H	0%
	Overall (n=3)	M	H	H	67%

* Degradation = alteration of the resident biota by pollution or some other deleterious biological effect.

a. Chemistry Relative Enrichment to Mean Values for the Reference site; ranking system described in Section 4.1.4.
   L = low, 0-5 X reference
   M = moderate, >5-50 X reference
   H = high, >50 X reference

b. Bioassay Responses (from Table 18)
   L = low, 0-2 responses
   M = moderate, >2-4 responses
   H = high, > 4-6 responses

c. Infauna Data Relative Categorization
   L = low, M = moderate, H = high } as defined in Section 4.3.3

d. Based on the following ratios:
   3 equal degrees = 100% agreement
   2 equal degrees = 67% agreement
   0 equal degrees = 0% agreement

effects thresholds determined in Puget Sound are presented in Table 25, together with the maximum levels (and station of occurrence) of each of the rated compounds that were observed in San Francisco Bay.

From this comparison, it is apparent that the concentrations of some of the substances measured in San Francisco Bay sediments were close to or exceeded the apparent effects threshold values (that had been determined in another system). The levels of mercury, zinc and the HPAHs were roughly equal to or exceeded the threshold values at Stations IS02 and IS05, while the other substances for which data were available were within a factor of two of the threshold values in the Islais Waterway sediments.

Recognizing the preliminary nature of these apparent effect threshold values and the fact that the Commencement Bay Waterways may be substantially different in many respects from San Francisco Bay, their applicability to the present study was considered with care. However, the threshold values did tend to support the selections of indicator chemicals used in this report and the conclusion that the chemical contamination of Islais Waterway was of toxicological concern. These data also show that widespread application and careful interpretation of Triad data from a variety of areas and for various purposes, if verified with laboratory exposure data, may lead to the development of field verified and defensible toxicity criteria for allowable levels of chemicals in sediments. Even if universally applicable apparent effects threshold values cannot be obtained, the approach may at least provide a method to weight chemical concentrations based on their apparent relative toxicity levels.

The Triad can be used to determine pollution-induced degradation both areally and temporally for a large number of sites (and/or stations) by generating indices that represent a single composite characterization of the chemistry, bioassay and benthic data. These composites can be primarily visual. For example, plotting the composites from each of the Triad components on scales with a common origin and placed at 120° from each other makes the value of each unit index the vertex of a triangle. Such a presentation is shown in Figures 30 and 31 for the nine stations and three sites in San Francisco Bay. Calculation of the area of the triangles for each of the three sites gives an estimate of the relative degradation of the sites as well as visually defining the characteristics of "background" or reference sites. Similar calculations can also be done for individual stations. This presentation still retains, however, information regarding how the Triad components vary among sites (and/or stations). On the basis of the present study, the Islais Waterway site was 58X more degraded than the San Pablo Bay site and 42X more degraded than the Oakland site. The Oakland site was 1.4X more degraded than the San Pablo Bay site. Changes in pollution-induced degradation over time can be assessed by comparing Triad values (=triangle areas) on the same scale over different time periods.

The data presentation provided in Figures 30 and 31 also provides a definitive test of the hypothesis that formed the basis of this study. This hypothesis was that all three types of Triad

Table 25. Comparisons of the "apparent effect threshold" values determined in Puget Sound with the maximum concentrations observed in San Francisco Bay

Substance	Apparent Effect Threshold (mg/kg)		Maximum Concentration, mg/kg, in San Francisco Bay (Station)
	Tetra Tech (1985)	Chapman (in press a)b	
Arsenic	93/85a	N.D.c	72 (IS09)
Copper	310	N.D.	130 (IS02)
Lead	669/330	100	223 (IS02)
Mercury	0.59/0.52	N.D.	1.20 (IS05) 0.57 (IS02)
Zinc	490/260	N.D.	321 (IS02)
LPAH	5.2	6.8	3.2 (IS02)
HPAH	12/17		12.06 (IS02) 11.83 (IS05)
PCB	0.42/1.1	0.8	0.255 (IS05)

a. The first value represents the threshold determined by amphipod and bivalve larvae sediment bioassays; the second value was determined from benthic community alterations. Data from Commencement Bay Waterways and nearshore areas.
b. Threshold determined based on combined broad-scale areal data for sediment bioassays and bottomfish liver abnormalities. Data from available sources for various Puget Sound embayments.
c. N.D. = not determined.

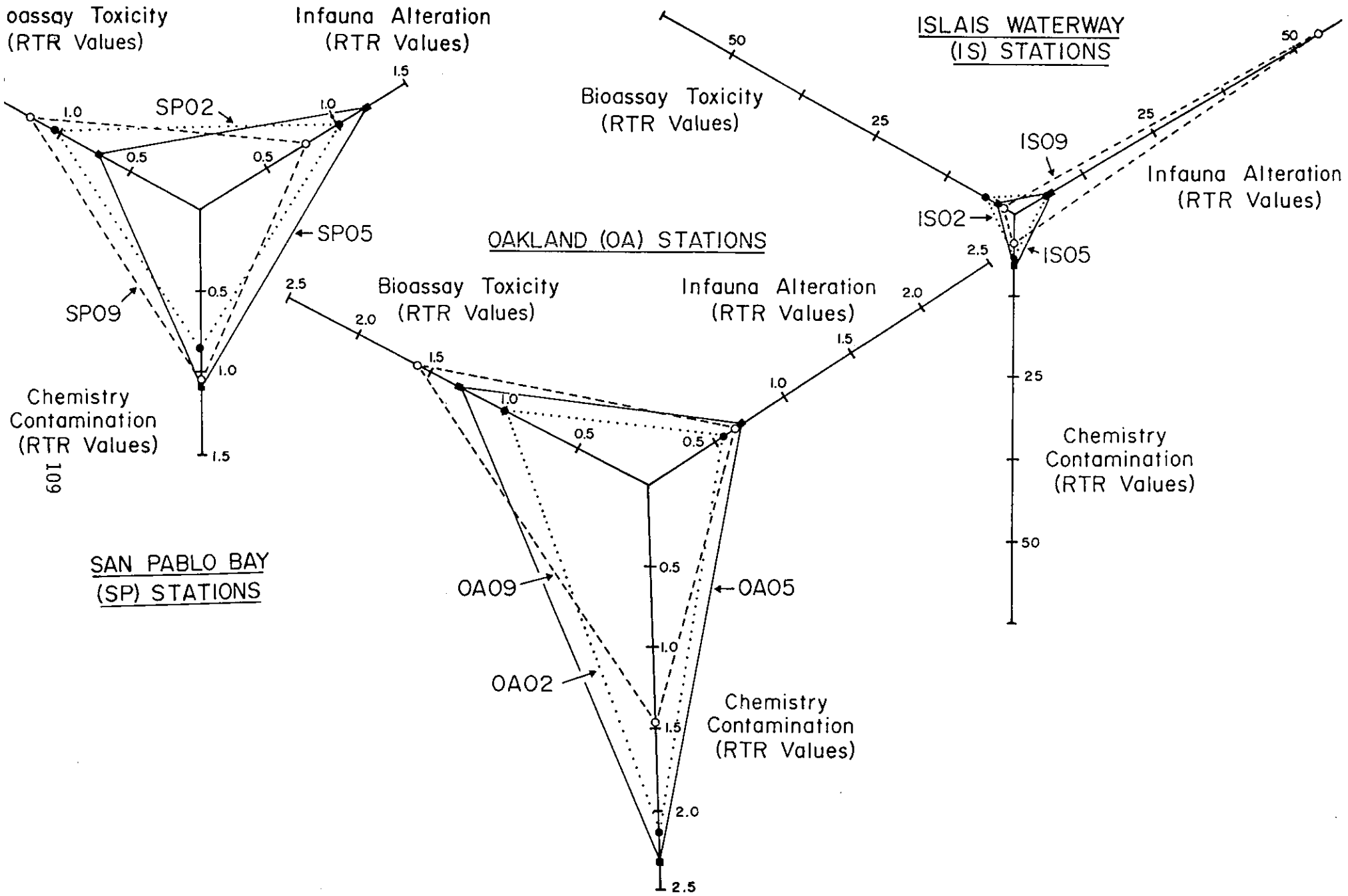


Figure 30. The Sediment Quality Triad determined for each station at each of the three study sites. Chemistry Ratio-to-Reference (RTR) values are from Table 17 (Aggregate Index 2); bioassay RTR values are from Table 20; infauna RTR values are from Table 23. The San Pablo Bay and Oakland stations are plotted on the same scale; Islais Waterway stations are plotted on a scale 1/25 the size of the other two sites.

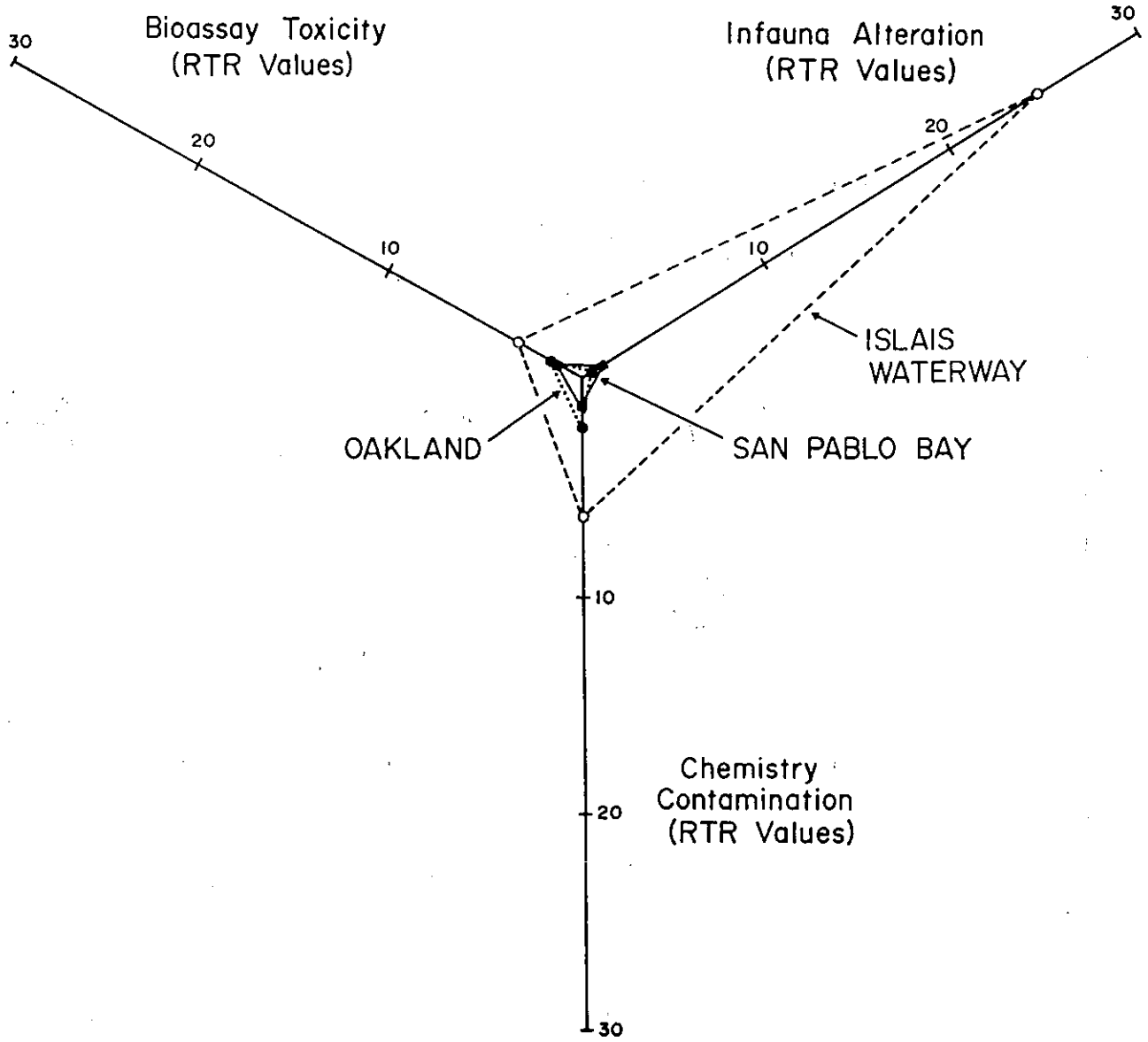


Figure 31. The Sediment Quality Triad determined for each of the three study sites. Chemistry Ratio-to-Reference (RTR) values are from Table 17 (Aggregate Index 2); bioassay RTR values are from Table 20; infauna RTR values are from Table 22.

measures (bioassay, chemistry, benthos) would be needed to determine pollution-induced degradation; that we could not predict one or two measures based on the data from just one. Our null hypothesis (Ho), expressed in terms of these two figures, would thus be that the traingles are parallel. For Ho to be accepted, then the lines forming the triangles in the case of each of the three within-site plots in Figure 30 and the between-site plot in Figure 31 should be parallel and should not cross each other. As is apparent from the figures, the lines are not parallel and multiple cross-overs occur. Thus Ho is rejected.

Based on the data, the hypothesis that formed the basis of this study is accepted. Specifically, all three components of the Triad are necessary to absolutely assess the degree of pollution-induced degradation. While even the Triad data do not "prove" a cause-and-effect relationship between the contamination and the biological disturbance at a site such as Islais Waterway, they do provide a high level of certainty that the Islais Waterway site is degraded. They also serve to rank Islais Waterway as the most degraded of the three sites studied in San Francisco Bay. The Triad approach is most important, however, not simply in establishing those sites that are more or less degraded, but in providing an objective identification of all sites where contamination is causing real harm.

4.4.2 The Sediment Quality Triad in the NOAA National Status and Trends Program

The NOAA National Status and Trends (NS&T) Program is described by Cantillo et al. (1984) as having the following major goal:

> To assess and document the status and long-term changes of environmental quality of the Nation's coastal and estuarine environment. Key questions the program intends to answer are 1) what are the current conditions of the Nation's coastal zone and 2) are these conditions getting better or worse?

The NS&T Program currently includes four major components:

1. chemical analyses of bottom sediments,
2. chemical analyses of bottomfish livers and bile,
3. determination of visible and histopathological lesions in bottomfish, and
4. chemical analyses of mussel tissues.

The only measure of biological effects included in the NS&T Program at present is the determination of lesions and other histopathological disorders in bottomfish. Measures of chemical bioaccumulation in livers and bile are only indirectly related to risks to human and other consumers, and cannot be directly related to biological/ecological effects. Moreover, the target fish selected for this monitoring are "highly motile and generally will range over the selected location seasonally and over an even wider area annually" (Cantillo et al., 1984). Thus it will be extremely difficult to determine any relationships between concentrations of chemical contaminants in sediments and lesions/histopathological disorders in the fish on

a station or site-specific basis. These relationships cannot be obtained by comparing body burden and sediment chemical levels as the disorders may be the result of chemicals not measured, of synergistic/antagonistic reactions, or of metabolic changes in chemicals once they enter the fish (Malins et al., 1984). Thus there is a clear need for some measure of biological effects that is as station- and site-specific as are the sediment chemistry measurements. Such a measure would provide necessary information on whether contamination at a station and/or site results in biological effects or toxicity.

This need for direct measures of biological effects can be supplied by including sediment bioassays in the NS&T Program. Based on the results of the present study, a minimum of two specific bioassays are recommended: the Rhepoxynius abronius 10-d test (Swartz et al., 1985) and the bivalve larvae 48-h test (Mitchell et al., 1985; ASTM, 1985b). The bivalve larvae test can be conducted using either mussels (e.g., Mytilus edulis) or oysters (e.g., Crassostrea gigas, C. virginica). Both bioassays comprise a lethal and sublethal component, and both are supported by an extensive data base, proven methods, and QA/QC procedures. They are relatively inexpensive and simple to implement (Chapman, in press b). Both bioassays should be used to provide confirmatory data and to eliminate potential problems associated with any one method (e.g., the R. abronius bioassay may be slightly influenced by grain size - Swartz et al., 1985a). In the present study, the data generated by these two bioassays, if used together, would have provided the same toxicity data as that provided by all four bioassays actually used. The other two bioassays used in the present study, clam reburial and harpacticoid copepod partial life-cycle testing, are not supported by such an extensive data base and the clam reburial bioassay may have methodological problems associated with its use (e.g., slow reburial in one clam control replicate in the present study).

Inclusion of sediment bioassays together with sediment chemistry determinations in the NS&T Program allows the resulting data to be analysed in terms of station and site-specific chemical toxicity. The additional inclusion of a benthic infaunal component in the NS&T Program would allow analysis of the data as a full Sediment Quality Triad. However, it is realized that a full benthic infaunal component would be extremely expensive, particularly when natural differences between areas and seasonal cycles must be taken into account. Accordingly, several options are possible. First, and most expensive, a full benthic infaunal sampling program (5 replicate 0.1 m^2 Van Veen grabs at each station) could be implemented, including complete taxonomic analysis. Second, as an alternative, these samples could be collected but only one sample per station (or per site) subjected to taxonomic analysis. Taxonomic analysis need not be complete, at least initially, and could simply involve determining the relative proportions of major faunal groups (i.e., Polychaeta, Mollusca, Amphipoda, others - cf. Figure 22) to determine major community changes. The remainder of the samples would be archived and available for possible future analysis dependent on the results of ongoing NS&T data gathering. Third, as another alternative, a detailed benthic infaunal sampling program (with full or partial taxonomic analysis) could be conducted at some subset of sites, after

the NS&T Program has been running for one or two years with sediment bioassays, to complement the chemistry and bioassay data. Fourth, as a final alternative, other available methods of determining benthic infaunal community structure, which are less expensive than traditional methods, could be refined for use in the NS&T Program. A promising candidate method for such use is Remote Ecological Monitoring of the Seafloor (REMOTS), which involves sediment profile photography combined with computer image analysis. This system is described by Rhoads and Germano (1982) and has been used on both the East Coast (Germano and Rhoads, 1984) and the West Coast of the United States (Science Applications International, 1985).

The usefulness of the Triad as part of the NS&T Program has been amply illustrated by the results of the present study, which included chemical analyses of all compounds listed under the NS&T Program, with the exception of microbial sewage tracers. Inclusion of sediment bioassays and of the Sediment Quality Triad in the NS&T Program allows for measurement of pollution-induced degradation on a temporal and spatial basis. As such, it fits the two key questions the Program intends to answer and also fits the stated future direction of this Program (Cantillo et al., 1984):

> The Status and Trends Program will...evolve as new technologies become available. The Program will put greater emphasis on... biological/ecological effects when reliable and meaningful measurements techniques can be developed.

Displaying the data generated by a Sediment Quality Triad comprised of sediment chemistry, sediment bioassay, and benthic infauna can take several forms depending on the level of synthesis desired and the assumptions that are made in deriving these syntheses.

The simplest method of data display involves no synthesis and no assumptions. The data are simply displayed as histograms showing chemical levels, percent effect on bioassay organisms (% mortality and avoidance of amphipods, % mortality and abnormality of bivalve larvae), and percent change in benthic infauna (incorporating as a minimum taxa richness, total abundance, relative abundance of major taxa, and dominance). These histograms could be displayed in either two or three dimensions, and compared to determine any correspondences and trends.

The data could also be normalized to reference site values, and presented as Ratio-to-Reference (RTR) values. However, care would have to be taken in such determinations to ensure that appropriate reference data were used (i.e., reference sites were as pristine as possible). Reference chemistry data for San Francisco Bay appear to be elevated in some metals compared to reference data for Puget Sound (cf. Table 15). It may thus be appropriate to use multiple reference sites for such comparisons, averaging the data from such sites.

Although weighting factors are not available for use with the chemical data, such factors could be used with the biological effects data. For instance, in the case of bioassays, sublethal effects are considered to be more sensitive indicators of toxicity than lethal effects and perhaps should be weighted accordingly. In the case of benthic infauna data, the presence/absence of amphipods may have more significance for determining pollution effects than similar data for other taxonomic groupings.

The Sediment Quality Triad can also be displayed as a tri-axis plot as shown in Figures 30 and 31. In this instance, bioassay, infauna and sediment chemistry data are compared for different stations and sites as a series of triangles. Determining the area of these triangles allows determination of the degree of pollution-induced degradation between stations and sites. The same sites and stations can also be compared over time, using this method to determine if conditions have changed, and the direction and magnitude of any change. This method of display incorporates the greatest degree of synthesis, as well as the greatest number of assumptions (i.e., categorization of each of the three Triad components as a single value).

The relative degree of synthesis and assumption comprising each of the methods of data display discussed above is illustrated in Figure 32. There are undoubtedly other methods of displaying/using these data that will be determined with future use of the Triad, and which can be incorporated into usage as appropriate. However, for the present we recommend that all three of these methods be used together to maximize the sensitivity and utility of the Triad as follows:

1. data histograms,
2. Ratio-to-Reference (RTR) values, and
3. tri-axis plots.

Weighting of biological effects data is not recommended until appropriate toxicological data are available to realistically determine such weighting. The data histograms and RTR values will provide summary data for determining the reasons for any significant areal or temporal changes in the tri-axis plots. Tri-axis plots allow the display of all three independent measures, but also allow some compilation or synthesis into one number (triangle area). The tri-axis plots effectively provide a proportional index of pollution-induced degradation, and it is in this context that the Sediment Quality Triad may ultimately prove to be the most important product of the NOAA National Status and Trends Program.

5.0 CONCLUSIONS

The following major conclusions can be derived from the results of this study related to the objective, a field trial of the Sediment Quality Triad:

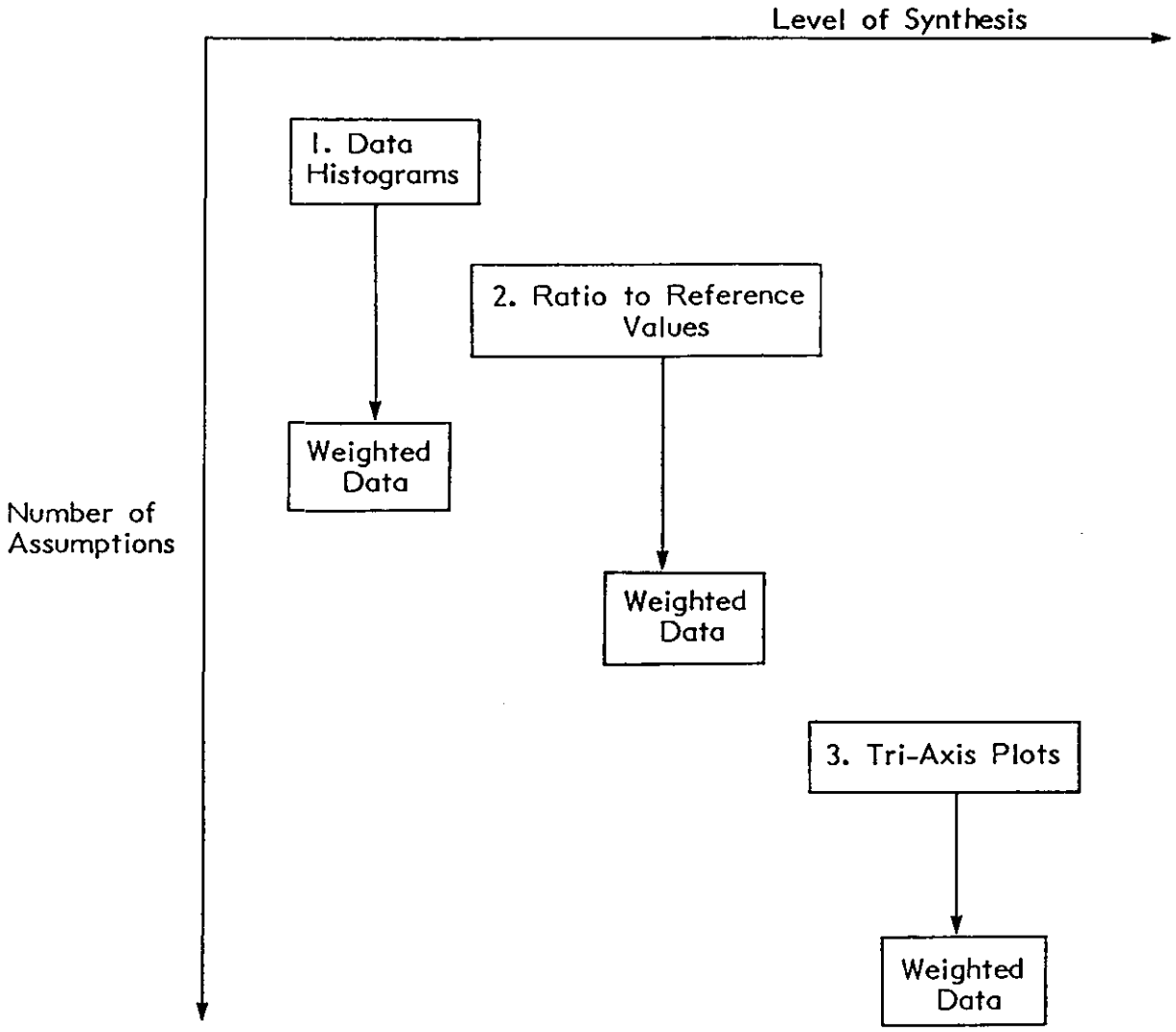


Figure 32. Methods of displaying Sediment Quality Triad data. The use of all methods with unweighted data is recommended

1. Chemical indices were suitable for identifying contaminated sites, but, alone based on our present knowledge were not suitable by themselves for determining whether the chemical concentrations at any site were sufficient to cause environmental problems. Bioassay indices were suitable for identifying toxic sites, but, alone, these results could not predict effects on natural communities. Benthic infaunal indices were suitable for identifying biologically altered sites, but, alone, these alterations could have been attributed to sediment texture differences between the three sites. Only the Sediment Quality Triad, which combined all of these indices, provided an absolute determination of pollution-induced degradation by matching elevated chemistry, increased toxicity and community alterations at affected stations and sites.

2. Sediment chemical concentrations, when converted to the ratios of the concentrations at a station and site compared to the mean levels at a reference site, provided suitable indices to identify stations and sites of contamination.

3. Of the four sediment bioassays used, those with the amphipod (Rhepoxynius abronius) and mussel larvae (Mytilus edulis), together, provided the same level of toxicity information for use in the Sediment Quality Triad as all four bioassays combined. These two bioassays each incorporated two usable measures of toxicity (lethal and sublethal) compared to the other two tests which only incorporated one such measure each.

4. The following four parameters proved particularly appropriate indices to summarize the benthic infaunal data: taxa richness, total abundance, relative abundance of major taxa, and dominance.

The following conclusion can be derived from the results of this study related to a secondary objective, providing data complementary to the NOAA National Status and Trends Program:

5. Of the chemicals that were measured, the substances that were particularly elevated in San Francisco Bay sediments, and which were considered to be of anthropogenic origin, were: lead, mercury, tin, silver, the low and high molecular weight aromatic hydrocarbons, the DDTs and the PCBs. These data cannot yet be compared to those from the NS&T Program, since the latter are not yet available.

The following conclusions can be derived from the results of this study related to another secondary objective, providing data on the sediment chemistry and biota of the San Francisco Bay system:

6. Using chemical indices of contamination, Islais Waterway was clearly identified as the most contaminated of the three sites sampled. The Oakland site was considerably less contaminated than Islais Waterway, and was only slightly more contaminated than the San Pablo Bay site.

7. Sediment chemical concentrations measured in all nine stations in San Francisco Bay were much lower than the maximum concentrations of many compounds measured in other areas of the West Coast (i.e., Puget Sound and the Southern California Bight).

8. The maximum concentrations of some metals and organic compounds in Islais Waterway, in particular mercury, zinc and the high molecular weight polyaromatic hydrocarbons, approached or exceeded apparent threshold levels as determined in Puget Sound. These threshold levels were not approached in the Oakland or San Pablo Bay sites, although biological effects (at a lower level) were also determined at these sites.

9. Sediment texture and organic matter content (as indicated by TOC) were strongly correlated. In addition, the concentrations of the chemical substances that were enriched in the sediments were strongly associated with the TOC phase. These strong relationships indicate that the grain-size, TOC and associated substances may have come from a single source, or from multiple sources discharging similar materials. The chemical substances that were identified at elevated concentrations (compared to the levels observed at the San Pablo Bay reference site) gave some indication that the source/sources may have been a mixture of municipal sewage and street runoff discharges.

10. Benthic taxa identified from the Bay were generally similar to those identified in previous studies. The open Bay sites were dominated by the amphipod Ampelisca abdita. Islais Waterway was dominated by the polychaete Capitella capitata. Compared to other West Coast areas (e.g., Puget Sound, the Southern California Bight), the San Francisco Bay benthic infauna are depauperate in terms of numbers of species present.

11. A new distributional record was recorded for the marine oligochaete Limnodriloides victoriensis. This species has not previously been collected south of Puget Sound.

6.0 RECOMMENDATIONS

The following recommendations are based on the results of this study:

1. The Sediment Quality Triad should be included as part of the NOAA National Status and Trends Program (NS&T), and should be used to measure pollution-induced degradation. This involves including, as a minimum, sediment bioassays as part of the NS&T Program. Benthic infauna studies should be conducted, at a minimum, at some selected sites to confirm the bioassay results. Several different options are provided in Section 4.4.2 for adding benthic infauna determinations to the NS&T Program. The Sediment Quality Triad is needed to address directly the identifications of problem sites by specifying the extent of contamination (i.e., in chemical analyses), by showing whether that contamination is capable of disrupting normal biological processes (i.e., in sediment bioassays), and by further confirming the

existence of a problem by demonstrating whether in fact disturbance of natural populations has occurred (e.g., the use of benthic community studies).

2. More than one sediment bioassay should be used to determine sediment toxicity. The amphipod (Rhepoxynius abronius or similar suitably sensitive species) and the bivalve larvae sediment bioassays (mussel larvae, Mytilus edulis, or oyster larvae, Crassostrea gigas or C. virginica) are recommended for inclusion in the National Status and Trends Program. These two techniques have been widely used, employ proven methods, and have well developed QA/QC procedures.

3. A number of different approaches/methodologies should be used in determining each component of the Sediment Quality Triad. For instance, more than one bioassay test should be used, and multiple methods of data analysis (both univariate and multivariate) should be used to assess alterations in benthic infaunal community structure. Joint interpretation of these approaches will serve to confirm trends and eliminate problems associated with some methods and not with others (cf. Section 4.4).

4. The Sediment Quality Triad should be used to determine differences in the levels of pollution-induced degradation on both an areal and temporal basis. Recommended methods of data display for such comparisons are detailed in Section 4.4.2.

5. Comparisons with reference site data (the Ratio-to-Reference, RTR, approach used in the present study) provided a useful technique to determine differences in chemical contamination, toxicity, and alterations in natural communities. This approach should be used in the NOAA National Status and Trends Program using either individual or multiple reference sites, as appropriate (cf. Section 4.1.4). The reference concentrations provide scaling factors for different concentration ranges, as well as a measure of the "enrichment" of the sediments. For the latter purpose, every effort should be made to use natural background concentrations for the reference levels (either from a single "clean" site or from averages of multiple regional "clean" sites).

6. Effort should be devoted to developing relationships between the absolute concentrations of chemical substances in the sediments and synoptic measures of environmental impact (e.g., sediment toxicity as determined through bioassays, and community changes as determined through benthic community alterations). Such efforts may yield usable criteria for acceptable/unacceptable concentrations of chemicals in sediments. These criteria would simplify the management and prioritization of corrective actions. Such efforts could also result in the simplification of the Sediment Quality Triad, if good correspondence is derivable between one or more components of the Sediment Quality Triad (e.g., between sediment bioassays and benthic infaunal changes).

7. The relationships between sediment texture, TOC and enriched chemicals appeared to be important in understanding the sources and transport of potentially toxic materials within the San Francisco Bay system. Future studies should further investigate these relationships and all such sediment pollution studies should measure texture and organic content together with other chemical measurements.

8. The present study was limited to only a few stations and sites. More complete studies should be conducted in San Francisco Bay to fully determine and prioritize pollution-degraded sites. Such studies should use the Sediment Quality Triad. As a first step in these studies, it is recommended that archived sediment chemistry and infauna samples collected during the present study be analysed.

9. Recent detailed chemical analyses in Puget Sound have identified phenol and substituted phenols as major contaminants in some areas (Tetra Tech, 1985). Because this class of compounds has received limited study, it appears likely that more frequent analyses would indicate that acidic organic contaminants are also significant in other coastal areas. Therefore, acidic organic compounds, including phenol and substituted phenols (e.g., methylated and chlorinated) should be added to the NOAA NS&T Program.

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APPENDIX B

Detailed Sediment Characterization Data

B.1 Sediment Conventionals and Grain Size
B.2 Major Elements
B.3 Minor (=Trace) Elements
B.4 Low Molecular Weight Aromatic Hydrocarbons (LPAH)
B.5 High Molecular Weight Aromatic Hydrocarbons (HPAH) and Associated Compounds
B.6 Pesticides and PCBs
B.7 Chemical QA/QC Results

Appendix B.1

Sediment Conventionals and Grain Size

Station	Conventionals				Grain-Size, %		
	TOC, %	Sulfide mg/kg	TVS, %	% Solids	% Sand	% Silt	% Clay
SP02	0.60	89.0	4.0	61.3	66.2	16.7	17.1
SP05	1.25	<5	6.6	44.9	18.6	37.7	43.8
SP09	1.46	<5	7.2	42.4	8.3	39.6	52.0
Average	1.10	29.7	5.9	49.5			
Std. Dev.	0.37	42.0	1.4	8.4			
DA02	1.31	9.3	7.9	38.0	6.1	37.8	56.1
DA05	1.10	<5	6.7	41.4	23.0	32.1	44.9
DA09	1.24	<5	6.8	37.1	12.9	37.0	50.1
Average	1.22	3.1	7.1	38.8			
Std. Dev.	0.09	4.4	0.5	1.9			
IS02	4.03	740.0	12.8	31.7	3.3	88.5	8.1
IS05	3.14	620.0	11.4	33.3	5.9	82.0	12.1
IS09	1.44	260.0	9.4	34.9	8.2	39.8	52.0
Average	2.87	540.0	11.2	33.3			
Std. Dev.	1.07	204.0	1.4	1.3			

Appendix B.2

Major Elements

	Major Elements, % dry mass							
Sample No.	Al	Si	Fe	Mn	Mg	Ca	Na	Ti
SP02	7.5	31.2	4.6	0.079	1.8	1.70	2.20	0.39
SP05	7.7	27.5	4.9	0.064	1.8	1.10	2.20	0.40
SP09	7.9	26.9	5.1	0.074	1.9	1.10	2.20	0.41
Average	7.7	28.5	4.9	0.072	1.8	1.30	2.20	0.40
Std. Dev.	0.2	1.9	0.2	0.006	.0	0.28	.00	0.01
OA02	9.9	33.6	6.2	0.076	2.4	1.40	3.20	0.49
OA05	7.2	27.9	4.3	0.051	1.7	1.10	2.30	0.36
OA09	7.6	27.4	4.6	0.064	1.8	1.20	2.90	0.37
Average	8.2	29.6	5.0	0.064	2.0	1.23	2.80	0.41
Std. Dev.	1.2	2.8	0.8	0.010	0.3	0.12	0.37	0.06
IS02	7.5	23.3	4.8	0.038	1.8	0.92	3.10	0.38
IS05	7.6	23.7	5.0	0.044	2.1	1.00	3.10	0.38
IS09	8.0	24.4	5.0	0.045	2.0	0.98	2.70	0.39
Average	7.7	23.8	4.9	0.042	2.0	0.97	2.97	0.38
Std. Dev.	0.2	0.5	0.1	0.003	0.1	0.03	0.19	.00

Appendix B.3

Minor (=Trace) Elements

	Minor Elements, mg/kg dry mass													
Station	Sb	As	Be	Cd	Cr	Cu	Pb	Hg	Ni	Se	Ag	Sn	Th	Zn
SP02	<50	44	<1	<1	72	30	18	0.09	76	<3	0.9	3.0	<2	86
SP05	<50	54	<1	<1	86	49	21	0.24	83	<3	1.1	5.4	<2	107
SP09	<50	70	<1	<1	93	53	25	0.31	85	<3	1.6	4.5	<2	114
Average	0	56	0	0	84	44	21	0.21	81	0	1.2	4.3	0	102
Std. Dev.	0	11	0	0	9	10	3	0.09	4	0	0.3	1.0	0	12
OA02	<50	64	<1	<1	95	51	33	0.28	84	<3	2.0	5.3	<2	122
OA05	<50	58	<1	<1	85	43	29	0.21	72	<3	1.7	5.4	<2	102
OA09	<50	49	<1	<1	90	45	30	0.29	76	<3	2.4	6.5	<2	109
Average	0	57	0	0	90	46	31	0.26	77	0	2.0	5.7	0	111
Std. Dev.	0	6	0	0	4	3	2	0.04	5	0	0.3	0.5	0	8
IS02	<50	57	<1	1	134	130	223	0.57	94	<3	8.1	17.0	<2	321
IS05	<50	66	<1	<1	146	98	115	1.20	96	<3	8.6	15.0	<2	225
IS09	<50	72	<1	<1	110	68	49	0.37	88	<3	4.0	8.0	<2	156
Average	0	65	0	0	130	99	129	0.71	93	0	6.9	13.3	0	234
Std. Dev.	0	6	0	1	15	25	72	0.35	3	0	2.1	3.9	0	68

Appendix B.4

Low Molecular Weight Aromatic Hydrocarbons (LPAH)

Low Molecular Weight Aromatic Hydrocarbons, ug/kg dry mass

Station	acenaphthene	anthracene	fluorene	naphthalene	1-methyl-naphthalene	2-methyl-naphthalene	2,6-dimethyl naphthalene	2,3,5-trimethyl naphthalene	phenanthrene	1-methyl-phenanthrene	Sum of Low Mol. Wgt. PAH
SP02	(.005	0.006	0.002	0.003	(.005	(.005	0.000	0.000	0.020	(.005	0.03
SP05	0.009	0.024	0.011	0.027	0.009	0.020	0.009	0.005	0.088	0.008	0.21
SP09	0.006	0.029	0.010	0.024	0.014	0.033	0.003	0.014	0.080	0.011	0.22
Average	0.005	0.020	0.008	0.018	0.008	0.018	0.004	0.006	0.063	0.006	0.16
Std. Dev.	0.004	0.010	0.004	0.011	0.006	0.014	0.004	0.006	0.030	0.005	0.09
DA02	0.016	0.060	0.019	0.051	0.052	0.023	0.014	0.007	0.172	0.018	0.43
DA05	0.016	0.056	0.018	0.048	0.029	0.048	0.009	0.006	0.149	0.019	0.40
DA09	0.012	0.040	0.014	0.048	0.015	0.043	0.006	0.005	0.128	0.012	0.32
Average	0.015	0.052	0.017	0.049	0.032	0.038	0.010	0.006	0.150	0.016	0.38
Std. Dev.	0.002	0.009	0.002	0.001	0.015	0.011	0.003	0.001	0.018	0.003	0.05
IS02	0.061	1.341	0.232	0.145	0.044	0.118	0.074	0.166	0.615	0.363	3.16
IS05	0.056	1.138	0.213	0.147	0.045	0.126	0.065	0.159	0.509	0.299	2.76
IS09	0.027	0.289	0.042	0.090	0.024	0.051	0.019	0.012	0.301	0.065	0.92
Average	0.048	0.923	0.162	0.127	0.038	0.098	0.053	0.112	0.475	0.242	2.28
Std. Dev.	0.015	0.456	0.085	0.026	0.010	0.034	0.024	0.071	0.130	0.128	0.97

Appendix B.5

High Molecular Weight Aromatic Hydrocarbons (HPAH) and Associated Compounds

	High Molecular Weight Aromatic Hydrocarbons, mg/kg dry mass								Other Hydrocarbons, mg/kg		
Station	chrysene	benzo(a)-pyrene	benzo(e)-pyrene	benzo(a) anthracene	dibenzo(a,h)-anthracene	fluoranthene	pyrene	Sum of High Mol. Wgt. PAH	biphenyl	perylene	coprostanol
SP02	0.028	0.036	0.018	0.016	0.005	0.053	0.068	0.224	(.005	0.061	0.162
SP05	0.094	0.148	0.092	0.060	0.028	0.183	0.242	0.847	0.007	0.095	0.527
SP09	0.093	0.156	0.083	0.062	0.027	0.014	0.239	0.674	0.003	0.091	0.753
Average	0.072	0.113	0.064	0.046	0.020	0.083	0.183	0.582	0.003	0.082	0.481
Std. Dev.	0.031	0.055	0.033	0.021	0.011	0.072	0.081	0.263	0.003	0.015	0.243
OA02	0.194	0.426	0.180	0.153	0.063	0.387	0.489	1.892	0.010	0.133	0.834
OA05	0.158	0.310	0.142	0.117	0.051	0.332	0.416	1.526	0.009	0.091	1.418
OA09	0.120	0.195	0.104	0.077	0.035	0.259	0.320	1.110	0.007	0.066	0.278
Average	0.157	0.310	0.142	0.116	0.050	0.326	0.408	1.509	0.009	0.097	0.843
Std. Dev.	0.030	0.094	0.031	0.031	0.011	0.052	0.069	0.319	0.001	0.028	0.465
IS02	2.208	1.314	0.820	1.199	0.229	3.628	2.666	12.064	0.035	0.243	31.546
IS05	2.126	1.256	0.689	1.138	0.299	3.712	2.605	11.825	0.027	0.225	26.105
IS09	0.702	0.702	0.365	0.421	0.124	0.871	1.292	4.477	0.017	0.169	5.450
Average	1.679	1.091	0.625	0.919	0.217	2.737	2.188	9.455	0.026	0.212	21.034
Std. Dev.	0.691	0.276	0.191	0.353	0.072	1.320	0.634	3.522	0.007	0.032	11.241

Appendix B.6

Pesticides and PCBs

Pesticides and PCBs, ug/kg dry mass

Station	trans-Chlordane	cis-Chlordane	p,p'-DDD	p,p'-DDE	p,p'-DDT	trans-Nonachlor	Total PCB
SP02	<0.14	<0.11	0.21	0.21	<0.10	<0.08	5.71
SP05	<0.14	<0.11	0.53	0.27	<0.10	<0.08	11.14
SP09	<0.14	<0.11	0.45	0.26	<0.10	<0.08	17.45
Average	0.00	0.00	0.40	0.25	0.00	0.00	11.43
Std. Dev.	0.00	0.00	0.14	0.03	0.00	0.00	4.80
OA02	<0.14	<0.11	1.00	0.29	0.24	<0.08	36.84
OA05	<0.14	<0.11	0.82	0.24	<0.10	<0.08	26.57
OA09	<0.14	<0.11	0.65	0.22	<0.10	<0.08	26.95
Average	0.00	0.00	0.82	0.25	0.08	0.00	30.12
Std. Dev.	0.00	0.00	0.14	0.03	0.11	0.00	4.75
IS02	2.02	2.24	0.98	1.32	0.63	1.07	179.81
IS05	1.08	1.08	1.44	1.29	0.87	0.48	255.26
IS09	<0.14	0.10	1.38	0.46	0.40	<0.08	57.31
Average	1.03	1.14	1.27	1.02	0.63	0.52	164.13
Std. Dev.	0.83	0.88	0.20	0.40	0.19	0.44	81.57

APPENDIX B.7

CHEMICAL QA/QC RESULTS

Duplicate and Spike Recoveries
for Metals, TOC and Sulfide

Results are in mg/kg dry weight.

Compound	Sample	A	B	Avg.	Spike	Target	% Recovery
Antimony	SP02	<50	<50	<50	129	240	54
Arsenic	SP02	44	45	44	67	21	110
Beryllium	SP02	<1	<1	<1	21	24	88
Cadmium	SP02	<1	<1	<1	20	24	83
Chromium	SP02	74	71	72	160	96	92
Copper	SP02	30	30	30	140	120	92
Lead	SP02	20	15	18	214	240	82
Mercury	SP02	0.08	0.10	0.09	0.42	0.33	100
Nickel	SP02	75	76	76	289	240	89
Selenium	SP02	<3	<3	<3	3.7	5.3	70
Silver	SP02	0.8	1.0	0.9	21.1	24	84
Thallium	SP02	<2	<2	<2	25	26	96
Zinc	SP02	86	85	86	285	240	83
Tin	SP02	3.4	2.7	3.0	272	285	94
TOC %	SP09	1.47	1.46	1.46	1.40	1.42	99
Sulfide	SP09	<5	<5	<5	-	-	-

APPENDIX B.7

CHEMICAL QA/QC RESULTS

Duplicate Results for
Hydrocarbons, Sample IS02

Compound	IS02 (ug)	Label Recovery (%)	IS02 Dup(ug)	Label Recovery (%)	IS02 Avg.(ug)
acenaphthene	1.9	58	1.9	60	1.8
anthracene	41	54	44	48	42.5
benzo(a)anthracene	67	62	73	86	70
benzo(a)pyrene	40	59	56	107	48
benzo(e)pyrene	27	*	25	*	26
biphenyl	1.1	*	1.1	*	1.1
chrysene	38	67	38	103	38
dibenzo(a,h)anthracene	7.4	*	7.1	*	7.25
2,6-dimethylnaphthalene	2.5	*	2.2	*	2.35
fluoranthene	120	61	110	82	115
fluorene	7.5	58	7.2	54	7.35
1-methylnaphthalene	1.5	*	1.3	*	1.4
2-methylnaphthalene	4.0	*	3.5	*	3.75
1-methylphenanthrene	11	*	12	*	11.5
naphthalene	4.7	56	4.5	64	4.6
perylene	7.1	*	8.3	*	7.7
phenanthrene	19	56	20	55	19.5
pyrene	84	65	85	80	84.5
2,3,5-trimethylnaphthalene	5.2	*	5.3	*	5.25
coprostanol	1200	*	800	*	1000

"*" means no label present.
Values reported are in total micrograms.

APPENDIX B.7

NMFS Duwamish III
Reference Sediment Chemical Composition
Compared to Weyerhaeuser Analysis

Compound	NMFS Reference Sediment			Weyerhaeuser Analytical Results (n=1)
	na	Mean	cv	
naphthalene	24	340b	37	140b
2-methylnaphthalene	23	160	22	170
1-methylnaphthalene	23	120	26	140
biphenyl	23	35	28	12
2,6-dimethylnaphthalene	23	75	12	18
acenaphthene	24	330	13	130
fluorene	24	340	19	140
phenanthrene	24	2,400	11	4,900
anthracene	24	660	57	1,200
1-methylphenanthrene	23	220	11	110
fluoranthene	24	3,800	13	7,600
pyrene	24	4,100	11	8,300
benz(a)anthracene	24	1,800	14	2,700
chrysene	24	3,000	17	4,700
benzo(e)pyrene	23	1,800	12	2,000
benzo(a)pyrene	24	2,000	10	3,400
perylene	23	600	15	390
dibenz(a,h)anthracene	24	340	22	270
coprostanol	11	860	36	1,300

a. n = the number of samples in which the compound was detected.
b. all results in ng/g dry weight.

APPENDIX C

Amphipod Bioassay Data Sheets

C1 Amphipod Bioassay Eh Data
C2 Amphipod Bioassay Data and Day 10 Water Quality

APPENDIX C1

AMPHIPOD BIOASSAY Eh DATA

		Day 0			Day 10
Sample I.D.		top (0 cm)	middle (1 cm)	bottom (2 cm)	top (0 cm)
Control	a	-130	-140	-150	-100
	b	- 80	-120	-150	-120
	c	- 80	- 80	- 90	+ 20
	d	-150	-150	-160	-150
	e	-100	-120	-140	-100
	f	- 70	-100	-140	-
SP02	a	- 90	- 90	-100	+ 80
	b	-120	-140	-150	+ 80
	c	-110	-110	-110	+ 90
	d	-110	-120	-150	+ 70
	e	-120	-120	-120	+ 50
	f	-100	-100	-100	+ 50
SP05	a	- 70	- 90	-100	+ 50
	b	-160	-160	-170	+ 50
	c	-110	-120	-130	+ 50
	d	-110	-110	-120	+ 40
	e	-100	-110	-130	+ 50
	f	-150	-150	-170	+ 50
SP09	a	- 60	- 60	- 80	+ 70
	b	- 70	- 70	- 70	+ 70
	c	- 70	- 70	- 80	+ 70
	d	-100	-100	-100	+ 70
	e	-100	-120	-140	+ 70
	f	-150	-150	-150	+ 70
0A02	a	-120	-150	-170	0
	b	-140	-150	-160	0
	c	-160	-170	-180	0
	d	-160	-180	-190	0
	e	-160	-160	-170	0
	f	-160	-160	-170	0
0A05	a	- 80	-160	-190	- 10
	b	-170	-180	-190	- 10
	c	-140	-170	-180	- 10
	d	-190	-190	-190	- 5
	e	-170	-180	-190	- 10
	f	-120	-100	-170	- 10

Sample I.D.		top (0 cm)	middle (1 cm)	bottom (2 cm)	top (0 cm)
0A09	a	-150	-150	-150	+ 30
	b	-160	-160	-180	- 60
	c	-150	-160	-160	- 40
	d	-120	-150	-170	- 30
	e	-160	-160	-170	- 20
	f	-170	-170	-170	- 15
IS02	a	-250	-270	-280	- 30
	b	-260	-280	-290	- 30
	c	-250	-280	-300	- 20
	d	-260	-280	-300	- 20
	e	-260	-300	-300	- 20
	f	-210	-270	-290	- 20
IS05	a	-300	-320	-330	+ 50
	b	-280	-310	-340	+ 50
	c	-300	-320	-340	+ 40
	d	-320	-320	-330	+ 40
	e	-300	-320	-340	+ 40
	f	-290	-300	-330	+ 30
IS09	a	-170	-200	-220	+ 20
	b	-180	-200	-210	+ 20
	c	-190	-200	-210	+ 20
	d	-170	-200	-210	+ 20
	e	-210	-210	-220	+ 10
	f	-180	-190	-200	+ 10

APPENDIX C2

E.V.S. CONSULTANTS
AMPHIPOD BIOASSAYS- TRIAD
BIOASSAY DATA AND DAY 10 WATER QUALITY

SAMPLE SP-01

LAB NO.	REP.	NUMBER OF AMPHIPODS EMERGED FROM SEDIMENTS AT DAYS 0-10											NUMBER ALIVE AT 10 DAYS	NUMBER FAILING TO REBURROW	WATER CHEMISTRY AT 10 D			
		0	1	2	3	4	5	6	7	8	9	10			TEMP (°C)	SAL (ppt)	D.O. (mg/L)	pH
	A		0	0	0	0	0	0	0	0	3	1	17		16	29	7.8	8.1
	B		0	0	0	0	2	0	0	0	0	0	19		16	29	7.8	8.1
	C		0	1	0	2	0	2	1	0	0	1	18		16	28	7.8	8.2
	D		0	0	0	0	0	0	0	0	2	0	20		16	28	7.8	8.2
	E		0	0	0	2	0	1	0	0	3	3	14		16	28	7.9	8.2

17.6 ± 2.3

SAMPLE SP-02

LAB NO.	REP.	NUMBER OF AMPHIPODS EMERGED FROM SEDIMENTS AT DAYS 0-10											NUMBER ALIVE AT 10 DAYS	NUMBER FAILING TO REBURROW	WATER CHEMISTRY AT 10 D			
		0	1	2	3	4	5	6	7	8	9	10			TEMP (°C)	SAL (ppt)	D.O. (mg/L)	pH
	A		2	2	4	4	4	4	5	0	0	0	16		16	28	7.8	8.2
	B		1	0	0	0	0	0	0	0	1	1	20		16	28	7.8	8.1
	C		0	2	1	1	1	2	1	3	1	0	17		16	28	6.4	8.0
	D		2	0	0	2	0	2	0	2	3	0	19		16	28	5.6	7.9
	E		0	1	0	0	0	0	0	2	1	1	19		16	28	7.8	8.2

18.2 ± 1.6

SAMPLE SP-03

LAB NO.	REP.	NUMBER OF AMPHIPODS EMERGED FROM SEDIMENTS AT DAYS 0-10											NUMBER ALIVE AT 10 DAYS	NUMBER FAILING TO REBURROW	WATER CHEMISTRY AT 10 D			
		0	1	2	3	4	5	6	7	8	9	10			TEMP (°C)	SAL (ppt)	D.O. (mg/L)	pH
	A		0	0	0	0	1	0	5	1	1	1	19		16	28	7.8	8.2
	B		1	1	0	1	0	0	0	0	0	0	18		16	28	7.8	8.2
	C		0	0	1	1	0	1	1	1	1	1	17		16	28	7.8	8.2
	D		2	0	1	1	1	2	0	1	2	1	18		16	28	7.6	8.1
	E		0	1	1	3	2	1	0	2	1	0	15		16	28	7.6	8.2

17.4 ± 1.5

SAMPLE SP-04

LAB NO.	REP.	NUMBER OF AMPHIPODS EMERGED FROM SEDIMENTS AT DAYS 1-10										NUMBER ALIVE AT 10 DAYS	WATER CHEMISTRY AT 10 D			
		1	2	3	4	5	6	7	8	9	10		TEMP (°C)	SAL (ppt)	D.O. (mg/L)	pH
	A	0	0	0	0	1	1	1	0	1	0	15	16	27	6.8	8.1
	B	0	1	1	0	1	0	1	0	0	0	20	16	27	7.7	8.2
	C	2	1	1	0	0	0	5	1	1	0	17	16	27	7.0	8.0
	D	0	1	1	0	0	2	1	2	5	6	9	16	27	7.8	8.1
	E	1	0	1	1	1	0	0	1	0	0	19	16	27	7.8	8.2

16.0 ± 4.4

SAMPLE SP-05

LAB NO.	REP.	NUMBER OF AMPHIPODS EMERGED FROM SEDIMENTS AT DAYS 1-10										NUMBER ALIVE AT 10 DAYS	WATER CHEMISTRY AT 10 D			
		1	2	3	4	5	6	7	8	9	10		TEMP (°C)	SAL (ppt)	D.O. (mg/L)	pH
	A	0	3	1	0	0	3	3	3	3	0	19	16	28	7.8	8.1
	B	0	0	0	*	3	1	1	1	1	0	18	16	28	7.7	8.1
	C	0	0	0	0	0	0	0	0	0	0	20	16	29	7.7	8.1
	D	0	0	*	*	*	1	0	0	0	0	19	16	28	7.8	8.2
	E	0	0	0	1	0	0	0	0	0	0	20	16	29	7.8	8.2

19.2 ± 0.8

* too cloudy to accurately count

SAMPLE SP-06

LAB NO.	REP.	NUMBER OF AMPHIPODS EMERGED FROM SEDIMENTS AT DAYS 1-10										NUMBER ALIVE AT 10 DAYS	WATER CHEMISTRY AT 10 D			
		1	2	3	4	5	6	7	8	9	10		TEMP (°C)	SAL (ppt)	D.O. (mg/L)	pH
	A	0	0	0	0	0	1	0	0	0	0	19	16	28	7.8	8.2
	B	0	2	1	0	1	1	1	1	1	0	19	16	28	7.6	8.1
	C	0	0	*	*	1	0	0	0	1	0	19	16	28	7.8	8.1
	D	0	0	0	0	0	0	0	0	0	0	19	16	28	7.8	8.1
	E	0	0	1	1	1	3	0	1	0	1	16	16	28	7.7	8.1

18.4 ± 1.3

* too cloudly to accurately count

SAMPLE SP-07

LAB NO.	REP.	NUMBER OF AMPHIPODS EMERGED FROM SEDIMENTS AT DAYS 1-10										NUMBER ALIVE AT 10 DAYS	WATER CHEMISTRY AT 10 D			
		1	2	3	4	5	6	7	8	9	10		TEMP (°C)	SAL (ppt)	D.O. (mg/L)	pH
	A	0	0	0	0	0	0	0	0	0	0	17	16	29	7.8	8.1
	B	0	0	*	0	0	1	1	0	0	0	16	16	28	7.7	8.2
	C	0	0	*	*	0	1	1	0	3	1	17	16	28	7.7	8.2
	D	0	0	*	1	0	1	1	2	1	0	17	16	28	7.7	8.1
	E	0	0	0	0	1	0	0	1	0	0	17	16	28	7.7	8.1

16.8 ± 0.4

* too cloudy to accurately count

SAMPLE SP-08

LAB NO.	REP.	NUMBER OF AMPHIPODS EMERGED FROM SEDIMENTS AT DAYS 1-10										NUMBER ALIVE AT 10 DAYS	WATER CHEMISTRY AT 10 D			
		1	2	3	4	5	6	7	8	9	10		TEMP (°C)	SAL (ppt)	D.O. (mg/L)	pH
	A	0	0	-	1	0	0	1	3	0	1	19	16	29	7.8	8.1
	B	0	0	-	0	0	0	1	1	0	0	19	16	28	7.7	8.1
	C	0	1	0	0	0	0	0	0	1	0	20	16	28	7.8	8.2
	D	0	0	-	2	1	0	0	1	0	0	6	16	30	7.8	8.2
	E	0	0	0	0	0	0	0	0	0	0	7	16	29	7.8	8.1

14.2 ±7.0

SAMPLE SP-09

LAB NO.	REP.	NUMBER OF AMPHIPODS EMERGED FROM SEDIMENTS AT DAYS 1-10										NUMBER ALIVE AT 10 DAYS	WATER CHEMISTRY AT 10 D			
		1	2	3	4	5	6	7	8	9	10		TEMP (°C)	SAL (ppt)	D.O. (mg/L)	pH
	A	0	1	2	1	2	1	1	1	0	1	18	16	28	7.8	8.1
	B	1	0	0	0	0	0	1	0	1	0	13	16	29	7.8	8.2
	C	0	0	0	0	0	0	0	3	2	0	17	16	28	7.8	8.1
	D	1	0	0	0	0	1	0	0	0	0	14	16	28	7.6	8.1
	E	0	0	1	0	0	1	3	1	0	0	14	16	28	7.8	8.2

15.2 ± 2.2

SAMPLE SP-10

LAB NO.	REP.	NUMBER OF AMPHIPODS EMERGED FROM SEDIMENTS AT DAYS 1-10										NUMBER ALIVE AT 10 DAYS	WATER CHEMISTRY AT 10 D			
		1	2	3	4	5	6	7	8	9	10		TEMP (°C)	SAL (ppt)	D.O. (mg/L)	pH
	A	1	0	0	1	1	1	0	0	0	0	18	16	29	7.8	8.2
	B	1	1	0	1	0	0	1	2	1	0	16	16	28	7.8	8.1
	C	0	0	0	1	0	1	0	3	1	1	19	16	28	7.6	8.1
	D	0	0	0	0	1	1	0	0	0	0	16	16	29	7.7	8.1
	E	0	0	0	0	0	1	0	0	0	1	20	16	28	7.7	8.1

17.8 ± 1.8

SAMPLE IS-01

LAB NO.	REP.	NUMBER OF AMPHIPODS EMERGED FROM SEDIMENTS AT DAYS 1-10										NUMBER ALIVE AT 10 DAYS	WATER CHEMISTRY AT 10 D			
		1	2	3	4	5	6	7	8	9	10		TEMP (°C)	SAL (ppt)	D.O. (mg/L)	pH
	A	11	13	11	12	10	11	11	11	11	12	0	16	28	7.7	8.4
	B	8	5	6	5	7	7	8	9	6	5	1	16	29	7.2	8.6
	C	10	4	13	13	13	12	13	6	9	8	1	16	28	7.2	8.4
	D	11	11	14	7	9	8	8	4	5	2	3	16	29	7.2	8.7
	E	14	10	13	10	7	12	12	9	6	3	0	16	29	7.4	8.4

1.0 ± 1.2

SAMPLE IS-02

LAB NO.	REP.	NUMBER OF AMPHIPODS EMERGED FROM SEDIMENTS AT DAYS 1-10										NUMBER ALIVE AT 10 DAYS	WATER CHEMISTRY AT 10 D			
		1	2	3	4	5	6	7	8	9	10		TEMP (°C)	SAL (ppt)	D.O. (mg/L)	pH
	A	5	8	6	9	4	10	10	9	10	11	1	16	28	7.2	8.5
	B	-	2	3	4	2	8	8	10	9	13	0	16	28	5.6	8.5
	C	4	4	3	4	11	7	10	8	8	8	3	16	28	7.0	8.5
	D	-	5	6	4	6	9	9	13	10	13	1	16	28	7.0	8.5
	E	-	0	1	6	7	8	8	11	10	12	0	16	28	7.2	8.6

1.0 ± 1.2

SAMPLE IS-03

LAB NO.	REP.	NUMBER OF AMPHIPODS EMERGED FROM SEDIMENTS AT DAYS 1-10										NUMBER ALIVE AT 10 DAYS	WATER CHEMISTRY AT 10 D			
		1	2	3	4	5	6	7	8	9	10		TEMP (°C)	SAL (ppt)	D.O. (mg/L)	pH
	A	1	0	1	1	0	3	1	3	2	5	15	16	29	7.0	8.7
	B	-	3	0	0	1	2	2	1	4	3	16	16	28	7.2	8.7
	C	3	8	10	2	6	10	2	7	10	3	11	16	28	7.2	8.2
	D	4	7	5	3	5	6	4	4	2	6	9	16	30	7.2	8.7
	E	8	6	7	12	12	10	10	12	12	8	1	16	29	7.0	8.7

10.4 ± 6.0

SAMPLE IS-04

LAB NO.	REP.	NUMBER OF AMPHIPODS EMERGED FROM SEDIMENTS AT DAYS 1-10										NUMBER ALIVE AT 10 DAYS	WATER CHEMISTRY AT 10 D			
		1	2	3	4	5	6	7	8	9	10		TEMP (°C)	SAL (ppt)	D.O. (mg/L)	pH
	A	12	15	17	18	14	16	17	17	15	11	0	16	29	6.4	8.2
	B	13	11	11	11	12	13	13	10	10	6	0	16	29	6.4	8.2
	C	11	4	6	7	7	3	2	0	0	0	0	16	29	5.8	8.1
	D	9	5	6	5	0	0	0	0	0	0	0	16	29	6.0	8.1
	E	10	4	2	3	0	2	0	0	0	0	0	16	29	6.6	8.2

0 ± 0

SAMPLE IS-05

LAB NO.	REP.	NUMBER OF AMPHIPODS EMERGED FROM SEDIMENTS AT DAYS 1-10										NUMBER ALIVE AT 10 DAYS	WATER CHEMISTRY AT 10 D			
		1	2	3	4	5	6	7	8	9	10		TEMP (°C)	SAL (ppt)	D.O. (mg/L)	pH
	A	2	0	1	0	3	1	0	3	3	1	15	16	29	7.1	8.2
	B	-	0	0	0	0	3	3	4	3	0	15	16	29	7.0	8.1
	C	2	0	1	0	4	3	1	2	3	1	15	16	29	7.0	8.2
	D	0	0	1	1	1	2	4	1	2	2	16	16	29	5.2	7.8
	E	0	0	1	4	4	5	5	3	2	0	15	16	29	6.8	8.1

15.2 ± 0.4

SAMPLE IS-06

LAB NO.	REP.	NUMBER OF AMPHIPODS EMERGED FROM SEDIMENTS AT DAYS 1-10										NUMBER ALIVE AT 10 DAYS	WATER CHEMISTRY AT 10 D			
		1	2	3	4	5	6	7	8	9	10		TEMP (°C)	SAL (ppt)	D.O. (mg/L)	pH
	A	1	0	0	0	0	2	0	1	1	0	19	16	29	7.0	8.1
	B	-	1	1	1	0	0	1	0	0	0	15	16	29	7.0	8.2
	C	-	0	0	2	0	1	0	0	0	1	15	16	29	6.0	7.8
	D	0	0	0	0	0	0	0	0	1	2	13	16	29	7.0	8.1
	E	0	0	0	0	0	1	0	0	0	0	17	16	29	7.0	8.1

15.8 ± 2.3

SAMPLE IS-07

LAB NO.	REP.	NUMBER OF AMPHIPODS EMERGED FROM SEDIMENTS AT DAYS 1-10										NUMBER ALIVE AT 10 DAYS	WATER CHEMISTRY AT 10 D			
		1	2	3	4	5	6	7	8	9	10		TEMP (°C)	SAL (ppt)	D.O. (mg/L)	pH
	A	1	2	5	2	2	0	0	0	0	0	11	16	28	7.2	7.9
	B	0	0	0	0	0	0	1	1	1	0	14	16	28	7.3	7.9
	C	0	0	0	0	2	3	2	2	2	0	14	16	28	7.3	7.9
	D	0	0	0	0	0	0	1	0	0	0	16	16	29	7.3	7.8
	E	-	0	1	0	0	1	0	1	3	0	16	16	28	7.2	7.4

14.2 ± 2.0

SAMPLE IS-08

LAB NO.	REP.	NUMBER OF AMPHIPODS EMERGED FROM SEDIMENTS AT DAYS 1-10										NUMBER ALIVE AT 10 DAYS	WATER CHEMISTRY AT 10 D			
		1	2	3	4	5	6	7	8	9	10		TEMP (°C)	SAL (ppt)	D.O. (mg/L)	pH
	A	14	16	2	3	1	0	1	0	0	1	9	16	29	7.2	8.3
	B	12	8	1	1	1	1	2	2	1	3	13	16	30	7.2	8.3
	C	11	0	0	0	0	1	0	3	4	3	13	16	29	7.2	8.4
	D	13	2	3	1	0	0	1	0	4	2	15	16	29	7.2	8.2
	E	-	4	1	0	1	1	1	2	3	3	19	16	29	7.2	8.3

13.8 ± 3.6

SAMPLE IS-09

LAB NO.	REP.	NUMBER OF AMPHIPODS EMERGED FROM SEDIMENTS AT DAYS 1-10										NUMBER ALIVE AT 10 DAYS	WATER CHEMISTRY AT 10 D			
		1	2	3	4	5	6	7	8	9	10		TEMP (°C)	SAL (ppt)	D.O. (mg/L)	pH
	A	0	0	0	0	0	1	2	1	0	1	13	16	29	7.0	8.7
	B	5	-	-	0	0	0	0	0	0	0	7	16	29	7.2	8.5
	C	0	0	0	0	0	0	0	1	0	1	11	16	29	7.2	8.5
	D	-	0	-	0	0	0	1	1	0	1	15	16	29	7.2	8.4
	E	-	2	1	1	2	2	1	3	2	0	17	16	29	7.0	8.1

12.6 ± 3.8

SAMPLE IS-10

LAB NO.	REP.	NUMBER OF AMPHIPODS EMERGED FROM SEDIMENTS AT DAYS 1-10										NUMBER ALIVE AT 10 DAYS	WATER CHEMISTRY AT 10 D			
		1	2	3	4	5	6	7	8	9	10		TEMP (°C)	SAL (ppt)	D.O. (mg/L)	pH
	A	0	0	0	0	0	1	0	2	1	0	8	16	29	7.0	7.9
	B	1	0	0	0	0	0	0	0	0	0	7	16	29	7.0	7.9
	C	0	0	0	0	0	1	0	0	1	0	11	16	29	7.2	7.1
	D	0	0	0	0	0	0	0	0	0	1	11	16	29	7.2	7.9
	E	0	0	0	0	1	0	0	0	0	0	13	16	29	7.0	7.9
												10.0 ± 2.4				

SAMPLE OA-1

LAB NO.	REP.	NUMBER OF AMPHIPODS EMERGED FROM SEDIMENTS AT DAYS 1-10										NUMBER ALIVE AT 10 DAYS	WATER CHEMISTRY AT 10 D			
		1	2	3	4	5	6	7	8	9	10		TEMP (°C)	SAL (ppt)	D.O. (mg/L)	pH
	A	0	0	0	0	1	1	0	0	0	0	19	16	29	5.8	7.9
	B	0	0	0	1	3	1	0	0	0	1	16	16	29	7.7	8.2
	C	0	0	2	0	0	0	2	2	2	0	17	16	30	7.9	8.3
	D	0	1	0	0	2	4	0	0	1	1	20	16	29	7.9	8.3
	E	0	0	0	0	0	0	0	1	0	0	18	16	29	7.9	8.3
												18.0 ± 1.6				

SAMPLE OA-2

LAB NO.	REP.	NUMBER OF AMPHIPODS EMERGED FROM SEDIMENTS AT DAYS 1-10										NUMBER ALIVE AT 10 DAYS	WATER CHEMISTRY AT 10 D			
		1	2	3	4	5	6	7	8	9	10		TEMP (°C)	SAL (ppt)	D.O. (mg/L)	pH
	A	0	0	0	0	2	3	3	1	1	2	17	16	29	8.0	8.3
	B	0	0	0	2	2	2	0	0	1	1	19	16	29	8.0	8.3
	C	0	0	1	0	1	2	1	0	0	1	19	16	29	8.0	8.3
	D	0	0	0	0	0	1	2	0	1	0	18	16	30	8.0	8.3
	E	0	0	0	0	0	1	0	1	1	1	18	16	29	8.0	8.4
												18.2 ± 0.8				

SAMPLE OA-3

LAB NO.	REP.	NUMBER OF AMPHIPODS EMERGED FROM SEDIMENTS AT DAYS 1-10										NUMBER ALIVE AT 10 DAYS	WATER CHEMISTRY AT 10 D			
		1	2	3	4	5	6	7	8	9	10		TEMP (°C)	SAL (ppt)	D.O. (mg/L)	pH
	A	0	0	0	1	0	1	0	0	1	1	20	16	29	8.0	8.2
	B	0	0	1	0	0	2	0	1	0	0	16	16	30	7.9	8.2
	C	0	1	1	0	0	1	0	0	1	0	19	16	30	7.9	8.2
	D	0	0	1	0	3	2	0	2	1	0	19	16	29	8.0	8.2
	E	0	0	0	0	0	0	0	0	0	2	18	16	29	8.0	8.3
												18.4 ± 1.5				

SAMPLE OA-4

LAB NO.	REP.	NUMBER OF AMPHIPODS EMERGED FROM SEDIMENTS AT DAYS 1-10										NUMBER ALIVE AT 10 DAYS	WATER CHEMISTRY AT 10 D			
		1	2	3	4	5	6	7	8	9	10		TEMP (°C)	SAL (ppt)	D.O. (mg/L)	pH
	A	0	0	0	1	1	2	1	2	2	1	16	16	29	7.9	8.3
	B	1	0	0	0	0	0	0	0	0	0	14	16	29	7.9	8.3
	C	0	0	0	0	4	2	0	1	0	2	15	16	29	7.9	8.3
	D	0	0	1	0	1	1	0	1	1	0	20	16	29	7.9	8.2
	E	0	1	1	1	0	1	0	2	0	0	15	16	29	7.9	8.3

16.0 ± 2.3

SAMPLE OA-5

LAB NO.	REP.	NUMBER OF AMPHIPODS EMERGED FROM SEDIMENTS AT DAYS 1-10										NUMBER ALIVE AT 10 DAYS	WATER CHEMISTRY AT 10 D			
		1	2	3	4	5	6	7	8	9	10		TEMP (°C)	SAL (ppt)	D.O. (mg/L)	pH
	A	0	0	1	0	2	3	1	0	1	1	18	16	29	7.7	8.2
	B	0	1	1	1	1	0	0	0	0	0	17	16	29	7.8	8.3
	C	0	0	0	0	0	1	0	0	0	0	18	16	29	6.8	8.2
	D	0	0	0	0	0	0	0	0	0	0	16	16	29	7.8	8.3
	E	0	0	0	0	0	0	5	0	2	1	18	16	29	7.9	8.3

17.4 ± 0.9

SAMPLE OA-6

LAB NO.	REP.	NUMBER OF AMPHIPODS EMERGED FROM SEDIMENTS AT DAYS 1-10										NUMBER ALIVE AT 10 DAYS	WATER CHEMISTRY AT 10 D			
		1	2	3	4	5	6	7	8	9	10		TEMP (°C)	SAL (ppt)	D.O. (mg/L)	pH
	A	0	0	5	1	3	3	4	4	2	2	17	16	29	7.8	8.3
	B	0	0	0	0	0	0	0	0	1	1	16	16	29	7.9	8.3
	C	0	0	0	0	0	1	2	0	0	0	18	16	29	7.9	8.4
	D	0	0	0	2	1	1	0	1	0	0	17	16	29	7.8	8.3
	E	13	4	3	1	0	1	0	1	0	0	12	16	29	7.8	8.3

16.0 ± 2.3

SAMPLE OA-7

LAB NO.	REP.	NUMBER OF AMPHIPODS EMERGED FROM SEDIMENTS AT DAYS 1-10										NUMBER ALIVE AT 10 DAYS	WATER CHEMISTRY AT 10 D			
		1	2	3	4	5	6	7	8	9	10		TEMP (°C)	SAL (ppt)	D.O. (mg/L)	pH
	A	1	0	0	1	0	1	1	1	1	0	15	16	29	7.8	8.3
	B	0	0	0	1	1	2	2	3	2	0	14	16	29	7.8	8.2
	C	0	1	0	0	0	0	2	1	2	0	16	16	29	7.8	8.3
	D	0	0	0	1	1	1	0	1	0	1	16	16	29	7.8	8.3
	E	0	0	1	0	0	0	0	0	0	0	17	16	29	7.8	8.3

15.6 ± 1.1

SAMPLE OA-8

LAB NO.	REP.	NUMBER OF AMPHIPODS EMERGED FROM SEDIMENTS AT DAYS 1-10										NUMBER ALIVE AT 10 DAYS	WATER CHEMISTRY AT 10 D			
		1	2	3	4	5	6	7	8	9	10		TEMP (°C)	SAL (ppt)	D.O. (mg/L)	pH
	A	0	0	0	0	0	0	0	1	1	1	20	16	29	7.8	8.3
	B	0	1	1	1	2	2	2	3	0	2	15	16	29	7.1	8.2
	C	0	0	0	0	1	1	0	1	3	0	18	16	29	7.7	8.3
	D	0	1	1	1	1	1	0	1	1	0	16	16	29	7.9	8.3
	E	0	3	0	0	0	1	1	1	2	0	19	16	29	7.7	8.2

17.6 ± 2.1

SAMPLE OA-9

LAB NO.	REP.	NUMBER OF AMPHIPODS EMERGED FROM SEDIMENTS AT DAYS 1-10										NUMBER ALIVE AT 10 DAYS	WATER CHEMISTRY AT 10 D			
		1	2	3	4	5	6	7	8	9	10		TEMP (°C)	SAL (ppt)	D.O. (mg/L)	pH
	A	0	7	1	3	2	4	3	6	5	1	17	16	28	7.6	8.3
	B	0	3	2	4	3	5	0	1	1	2	18	16	28	7.3	8.2
	C	5	3	0	2	0	2	0	0	1	0	17	16	28	7.8	8.3
	D	0	-	0	1	2	1	2	2	3	1	18	16	29	7.7	8.3
	E	0	2	1	1	3	2	0	2	4	1	17	16	29	7.8	8.3

17.4 ± 0.5

SAMPLE OA-10

LAB NO.	REP.	NUMBER OF AMPHIPODS EMERGED FROM SEDIMENTS AT DAYS 1-10										NUMBER ALIVE AT 10 DAYS	WATER CHEMISTRY AT 10 D			
		1	2	3	4	5	6	7	8	9	10		TEMP (°C)	SAL (ppt)	D.O. (mg/L)	pH
	A	0	0	1	0	0	0	0	1	0	0	19	16	29	7.8	8.4
	B	0	0	0	0	0	0	0	0	0	0	19	16	30	7.6	8.3
	C	3	0	3	3	2	1	0	0	1	0	20	16	29	7.8	8.3
	D	0	0	1	3	0	0	0	0	0	0	14	16	29	7.8	8.3
	E	0	0	0	2	0	0	1	0	0	0	17	16	20	7.8	8.4

17.8 ± 2.4

SAMPLE CONTROL

LAB NO.	REP.	NUMBER OF AMPHIPODS EMERGED FROM SEDIMENTS AT DAYS 1-10										NUMBER ALIVE AT 10 DAYS	WATER CHEMISTRY AT 10 D			
		1	2	3	4	5	6	7	8	9	10		TEMP (°C)	SAL (ppt)	D.O. (mg/L)	pH
	A	*10	4	4	3	3	4	4	4	4	1	16	16	29	8.1	8.4
	B	1	1	1	1	1	1	1	1	1	1	19	16	29	8.1	8.3
	C	0	0	0	1	1	1	1	1	1	0	19	16	29	8.0	8.3
	D	0	1	1	1	1	1	1	1	1	1	20	16	30	8.0	8.3
	E	0	0	0	0	0	0	0	0	0	1	20	16	30	8.0	8.4

* Air Failure

18.8 ± 1.6

E.V.S. CONSULTANTS

AMPHIPOD BIOASSAY

DAILY WATER CHEMISTRY MONITORING

LAB NO.	SAMPLE I.D.	TEMPERATURE (°C)											SALINITY (ppt)											DISSOLVED OXYGEN (mg/L)											pH										
		0	1	2	3	4	5	6	7	8	9	10	0	1	2	3	4	5	6	7	8	9	10	0	1	2	3	4	5	6	7	8	9	10	0	1	2	3	4	5	6	7	8	9	10
	IS-01		15.5	15.5	15.5	15	15	15.5	16	16	16	16		30	29	29	29	29	30	29	30	30	29		8.0	8.0	8.0	8.0	8.0	8.0	8.0	7.6	7.6	7.4	7.2		8.3	8.3	8.2	8.5	8.3	8.5	8.5	8.4	8.8	8.4
	IS-02		15.5	15.5	15.5	15	15	15.5	16	16	16	16		28	28	29	29	29	29	28	28	29	28		3.4	5.1	4.6	7.2	8.0	7.9	8.0	8.0	7.7	7.2		7.9	7.9	7.8	8.5	8.5	8.6	8.7	8.6	8.6	8.5
	IS-03		15.5	15.5	15.5	15	15	15.5	16	16	16	16		29	29	30	30	29	30	30	29	29	29		7.6	7.8	7.7	8.0	8.0	8.1	7.9	7.9	7.6	7.2		8.3	8.2	8.1	8.5	8.3	8.5	8.5	8.5	8.8	8.6
	IS-04		15.5	15.5	15.5	15	15	15.5	16	16	16	16		29	29	29	29	29	30	29	29	31	30		8.0	8.0	8.0	8.0	8.0	8.0	7.9	7.9	7.8	7.0		8.4	8.4	8.2	8.5	8.4	8.5	8.6	8.4	8.5	8.2
	IS-05		15.5	15.5	15.5	14.5	14.5	15.5	16	16	16	16		29	29	29	29	29	30	29	29	31	29		8.0	7.2	8.0	8.0	8.0	8.0	7.9	7.8	7.8	7.0		8.4	8.3	8.2	8.4	8.3	8.4	8.4	8.5	8.8	8.4
	IS-06		15.5	15.5	15.5	14.5	14.5	15.5	16	16	16	16		29	29	29	29	29	30	28	27	27	26		8.0	8.0	8.0	7.4	8.0	8.0	7.9	7.9	7.8	7.2		8.4	8.4	8.2	8.4	8.5	8.5	8.5	8.5	8.7	8.4
	IS-07		15.5	15.5	15.5	14.5	14.5	15.5	15.5	16	16	16		29	29	29	29	30	30	30	29	30	29		8.0	7.4	7.8	7.0	8.0	8.0	7.9	7.8	7.8	7.2		8.3	8.2	8.1	8.3	8.2	8.4	8.4	8.3	8.4	8.2
	IS-08		15.5	15.5	15	14.5	14.5	15	15.5	16	16	16		29	29	29	29	30	30	30	30	30	30		8.0	8.0	8.0	8.0	8.0	8.1	8.0	7.8	7.8	7.2		8.5	8.3	8.2	8.5	8.3	8.5	8.7	8.8	9.0	8.5
	IS-09		15.5	15	15	14.5	14.5	15	15.5	16	16	16		29	29	30	30	30	30	30	30	30	30		8.2	8.0	8.0	8.0	8.0	8.0	8.0	7.8	7.8	7.0		8.4	8.3	8.1	8.4	8.3	8.5	8.7	8.8	8.4	8.1
	IS-10		15.5	15	15	14.5	14.5	15	15.5	16	16	16		29	29	30	30	30	30	30	30	30	30		8.2	8.0	8.0	8.0	8.0	8.0	8.0	7.9	7.8	7.0		8.4	8.3	8.1	8.4	8.3	8.5	8.5	8.5	8.8	8.4

E.V.S. CONSULTANTS

AMPHIPOD BIOASSAY

DAILY WATER CHEMISTRY MONITORING

LAB NO.	SAMPLE I.D.	TEMPERATURE (°C)											SALINITY (ppt)											DISSOLVED OXYGEN (mg/L)											pH										
		0	1	2	3	4	5	6	7	8	9	10	0	1	2	3	4	5	6	7	8	9	10	0	1	2	3	4	5	6	7	8	9	10	0	1	2	3	4	5	6	7	8	9	10
	SP-01		14.5	14.5	14.5	14	15	15.5	15.5	16	16	16	28	28	29	29	29	29	29	29	29	29	29		8.2	8.1	8.0	8.0	8.2	8.0	8.0	7.9	7.8	7.8		8.3	8.2	8.0	8.2	8.1	8.3	8.3	8.2	8.3	8.1
	SP-02		14.5	14.5	14.5	14	15	15.5	15.5	16	16	16	28	28	29	29	28	28	28	29	29	28		8.2	8.1	8.0	8.0	8.2	8.0	7.9	7.9	7.8	7.7		8.3	8.2	8.1	8.2	8.2	8.4	8.3	8.1	8.3	8.2
	SP-03		14.5	14.5	14.5	14	15	15.5	15.5	16	16	16	28	28	30	30	29	29	29	29	29	29		8.4	8.4	8.6	8.0	8.2	8.0	8.0	7.9	7.8	7.7		8.2	8.0	7.9	8.4	8.2	8.4	8.3	8.1	8.3	8.3
	SP-04		14.5	14.5	14.5	14	15	15.5	15.5	16	16	16	28	28	29	29	28	24	28	28	28	24		8.2	7.8	8.0	8.0	8.0	8.0	8.0	8.0	7.4	7.2		8.1	8.2	8.0	8.1	8.1	8.3	8.3	8.2	8.2	8.1
	SP-05		14.5	14.5	14.5	14.5	15	15.5	15.5	16	16	16	28	28	30	30	28	28	29	29	29	28		8.2	8.2	7.2	8.0	8.0	8.0	7.9	7.8	7.6	7.8		8.3	8.3	8.0	8.3	8.2	8.4	8.3	8.2	8.2	8.2
	SP-06		16	16	16	16	16	16	16	16.5	16	16	28	28	30	30	29	29	28	29	29	28		8.0	7.8	7.6	7.6	7.6	7.9	7.6	7.9	7.6	7.7		8.1	8.2	8.0	8.2	8.1	8.3	8.1	8.2	8.1	8.1
	SP-07		16	16	16	15.5	16	16	16	16.5	16	16	28	28	30	30	29	29	29	29	29	28		8.0	7.9	7.9	7.8	7.7	8.0	7.7	7.8	7.8	7.6		8.1	8.3	8.1	8.3	8.1	8.4	8.3	8.2	8.3	8.2
	SP-08		16	16	16	15.5	16	16	16	16.5	16	16	28	28	28	29	30	29	29	30	30	29		8.0	8.0	7.9	7.8	8.0	8.0	7.9	7.8	7.8	7.7		8.1	8.3	8.1	8.4	8.2	8.4	8.4	8.3	8.3	8.2
	SP-09		16	16	16	15.5	16	16	16	16.5	16	16	8	28	30	30	30	29	29	30	30	29		8.0	8.0	8.0	8.0	7.6	7.2	7.9	7.8	7.8	6.9		8.1	8.3	8.1	8.3	8.1	8.2	8.4	8.3	8.2	8.1
	SP-10		16	16	16	15.5	16	16	16	16.5	16	16	28	28	29	29	29	29	29	29	29	29		8.2	8.0	7.9	8.0	7.8	7.9	7.9	7.8	7.8	7.7		8.1	8.3	8.1	8.3	8.1	8.3	8.4	8.3	8.3	8.2

E.V.S. CONSULTANTS

AMPHIPOD BIOASSAY

DAILY WATER CHEMISTRY MONITORING

LAB NO.	SAMPLE I.D.	TEMPERATURE (°C)											SALINITY (ppt)											DISSOLVED OXYGEN (mg/L)											pH										
		0	1	2	3	4	5	6	7	8	9	10	0	1	2	3	4	5	6	7	8	9	10	0	1	2	3	4	5	6	7	8	9	10	0	1	2	3	4	5	6	7	8	9	10
	OA-01		16	16	16	15.5	15.5	16	16	16	16.5	16		30	30	30	30	30	30	30	29	30	30		8.2	8.0	7.9	7.8	8.0	8.0	7.9	7.8	7.8	7.9		8.3	8.3	8.1	8.1	8.2	8.1	8.1	8.3	8.3	8.3
	OA-02		16	16	16	15.5	15.5	16	16	16	16.5	16		29	28	30	30	29	30	30	30	30	29		8.2	8.0	8.0	8.0	8.0	8.0	8.0	7.9	7.8	8.0		8.3	8.3	8.1	8.1	8.3	8.1	8.3	8.3	8.1	8.1
	OA-03		16	16	16	15.5	15.5	16	16	16	16.5	16		28	29	30	30	29	29	29	29	29	29		8.1	8.0	7.7	7.8	8.0	8.0	7.8	7.6	7.8	8.1		8.3	8.3	8.1	8.1	8.3	8.1	8.1	8.2	8.1	8.2
	OA-04		16	16	15.5	15.5	15.5	16	16	16	16.5	16		29	29	30	30	30	30	30	30	30	29		8.1	8.0	8.0	8.0	8.0	8.0	7.9	7.8	7.8	7.9		8.1	8.3	8.1	8.1	8.3	8.5	8.5	8.3	8.3	8.2
	OA-05		16	16	15.5	15.5	15	16	16	16	16	16		29	29	30	30	30	30	30	30	30	30		8.2	8.0	8.0	8.0	8.0	8.1	7.9	7.8	7.8	7.9		8.3	8.3	8.1	8.1	8.3	8.5	8.5	8.3	8.3	8.3
	OA-06		16	16	15.5	15	15	16	16	16	16	16		28	29	30	30	30	30	30	30	30	30		8.2	8.0	8.0	8.0	8.0	8.1	7.9	7.9	7.8	7.8		8.4	8.3	8.2	8.5	8.3	8.5	8.4	8.4	8.5	8.4
	OA-07		16	16	15.5	15	15	16	16	16	16	16		30	29	30	30	30	30	30	30	30	29		8.2	7.8	6.8	8.0	8.0	8.0	7.9	7.8	7.8	7.9		6.9	6.2	8.0	8.1	8.2	8.3	8.5	8.4	8.1	8.3
	OA-08		16	16	15	15	15	15.5	15.5	16	16	16		29	29	30	30	29	29	29	30	30	29		8.2	8.0	8.0	8.0	8.0	8.0	8.0	8.0	7.8	7.9		8.1	8.3	8.1	8.1	8.3	8.5	8.5	8.4	8.1	8.4
	OA-09		15.5	16	15	15	15	15.5	15.5	16	16	16		30	29	30	30	30	30	30	30	30	30		8.1	8.0	8.0	8.0	8.0	8.0	7.6	8.0	7.8	7.8		8.3	8.3	8.1	8.4	8.3	8.5	8.3	8.4	8.4	8.4
	OA-10		15.5	16	15	15	15	15.5	15.5	16	16	16		28	28	28	28	28	29	29	28	29	28		8.2	8.1	8.0	8.0	8.0	8.0	7.7	7.7	7.9	7.9		8.3	8.3	8.1	8.1	8.3	8.4	8.3	8.3	8.3	8.3

E.V.S. CONSULTANTS

AMPHIPOD BIOASSAY

DAILY WATER CHEMISTRY MONITORING

LAB NO.	SAMPLE I.D.	TEMPERATURE (°C)											SALINITY (ppt)											DISSOLVED OXYGEN (mg/L)											pH										
		0	1	2	3	4	5	6	7	8	9	10	0	1	2	3	4	5	6	7	8	9	10	0	1	2	3	4	5	6	7	8	9	10	0	1	2	3	4	5	6	7	8	9	10
	CONTROL		15.5	15.5	15.5	15	15	15.5	15.5	16	16	16		28	29	29	29	29	29	29	29	29	29		8.1	8.0	8.0	8.0	8.0	8.0	8.0	7.9	7.8	7.9		8.4	8.4	8.2	8.5	8.3	8.5	8.5	8.5	8.5	8.4

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APPENDIX D

Mussel Larvae Bioassay Data Sheets

D1 Water Quality Measurements in the Mussel Larvae Bioassay After 48 h
D2 Mussel Larvae Bioassay Data

APPENDIX DI

WATER QUALITY MEASUREMENTS IN THE MUSSEL LARVAE BIOASSAY AFTER 48 H

Station	Replicate	pH[a]	Salinity[b] (ppt)	Dissolved Oxygen[c] (mg/L)	Temperature (°C)
Seawater Control	A	8.4	28	7.0	20.0
	B	8.4	27	7.0	20.0
	C	8.4	28	7.0	19.5
	D	8.4	28	7.0	19.5
	E	8.4	28	7.1	19.5
Sediment Control	A	8.3	28	6.2	19.5
	B	8.3	28	6.2	19.5
	C	8.3	28	6.4	19.5
	D	8.3	28	6.2	19.0
	E	8.3	28	6.2	19.0
SP02	A	8.2	28	6.0	19.5
	B	8.1	28	6.0	19.0
	C	8.2	28	5.7	19.0
	D	8.2	28	5.7	19.0
	E	8.1	28	5.8	19.0
SP05	A	8.2	28	6.2	19.0
	B	8.2	28	6.3	19.0
	C	8.2	28	6.2	19.5
	D	8.2	28	6.2	20.0
	E	8.2	28	6.2	20.5
SP09	A	8.2	28	6.1	20.0
	B	8.2	28	6.2	19.0
	C	8.2	28	6.2	19.5
	D	8.2	28	6.2	20.0
	E	8.2	28	6.0	20.0
0A02	A	8.2	28	5.8	19.0
	B	8.2	28	5.6	19.0
	C	8.2	28	5.8	19.0
	D	8.2	28	5.7	19.0
	E	8.2	28	6.0	19.0
0A05	A	8.3	28	6.0	19.0
	B	8.3	28	5.9	19.0
	C	8.3	28	6.0	19.0
	D	8.3	28	5.9	19.0
	E	8.3	28	6.1	19.0

Station	Replicate	pH[a]	Salinity[b] (ppt)	Dissolved Oxygen[c] (mg/L)	Temperature (oC)
0A09	A	8.2	28	5.5	19.0
	B	8.2	28	5.6	19.0
	C	8.2	28	5.8	19.0
	D	8.2	28	5.8	19.0
	E	8.3	28	6.0	19.0
IS02	A	8.1	28	4.8	19.0
	B	8.1	28	4.8	19.0
	C	8.1	28	5.0	19.0
	D	8.1	28	5.0	19.0
	E	8.1	28	5.4	19.0
IS05	A	8.2	28	4.8	19.0
	B	8.1	28	5.2	18.0
	C	8.2	28	5.0	19.0
	D	8.2	28	4.8	18.5
	E	8.1	28	4.9	18.0
IS09	A	8.2	28	5.3	18.5
	B	8.1	28	5.4	18.5
	C	8.2	28	5.1	18.5
	D	8.2	28	5.2	18.0
	E	8.2	28	5.2	18.5

a. adjusted initially to 8.4
b. adjusted initially to 28 ppt
c. adjusted initially to 7.5 mg/L

APPENDIX D2

MUSSEL LARVAE BIOASSAY DATA

Station	Replicate	Total Larvae	Normal Larvae Total	Normal Larvae %	Abnormal Larvae Total	Abnormal Larvae %	Mean Values: No. of Larvae	Mean Values: Percent Abnormal	Mean Values: % Relative Survival[a]
Seawater Control	A	552	510	92.4	42	7.6			
	B	519	494	95.2	25	4.8			
	C	456	429	94.1	27	5.9			
	D	495	472	95.4	23	4.6			
	E	507	481	94.9	26	5.1	506	5.6	100
Sediment Control	A	357	332	93.0	25	7.0			
	B	476	442	92.9	34	7.1			
	C	265	244	92.1	21	7.9			
	D	340	312	91.8	28	8.2			
	E	418	390	93.3	28	6.7	371	7.4	73
SP02	A	220	183	83.2	37	16.8			
	B	309	273	88.3	36	11.7			
	C	327	279	85.3	48	14.7			
	D	273	234	85.7	39	14.3			
	E	310	280	90.3	30	9.7	288	13.4	57
SP 05	A	432	394	91.2	38	8.8			
	B	417	388	93.0	29	7.0			
	C	483	457	94.6	26	5.4			
	D	369	338	91.6	31	8.4			
	E	391	356	91.0	35	9.0	418	7.7	83

Station	Replicate	Total Larvae	Normal Larvae Total	Normal Larvae %	Abnormal Larvae Total	Abnormal Larvae %	Mean Values: No. of Larvae	Mean Values: Percent Abnormal	Mean Values: % Relative Survival[a]
SP09	A	208	184	88.5	24	11.5			
	B	316	279	88.3	37	11.7			
	C	321	280	87.2	41	12.8			
	D	251	211	84.1	40	15.9			
	E	192	145	75.5	47	24.5	258	15.3	51
0A02	A	212	185	87.3	27	12.7			
	B	247	216	87.4	31	12.6			
	C	261	215	82.4	46	17.6			
	D	318	278	87.4	40	12.6			
	E	203	168	82.8	35	17.2	248	14.5	49
0A05	A	140	104	74.3	36	25.7			
	B	94	63	67.0	31	33.0			
	C	103	77	74.8	26	25.2			
	D	114	85	74.6	29	25.4			
	E	157	135	86.0	22	14.0	122	24.7	24
0A09	A	174	140	80.5	34	19.5			
	B	129	87	67.4	42	32.6			
	C	190	169	88.9	21	11.1			
	D	184	160	87.0	24	13.0			
	E	171	141	82.5	30	17.5	170	18.7	34
IS02	A	36	13	36.1	23	63.9			
	B	58	19	32.8	39	67.2			
	C	14	6	42.9	8	57.1			
	D	27	5	18.5	22	81.5			
	E	16	5	31.2	11	68.8	30	67.7	6

Station	Replicate	Total Larvae	Normal Larvae Total	Normal Larvae %	Abnormal Larvae Total	Abnormal Larvae %	Mean Values: No. of Larvae	Mean Values: Percent Abnormal	Mean Values: % Relative Survival[a]
IS05	A	7	2	28.6	5	71.4			
	B	3	1	33.3	2	66.7			
	C	22	7	31.8	15	68.2			
	D	9	1	11.1	8	88.9			
	E	41	27	65.9	14	34.1	16	65.9	3
IS09	A	81	56	69.1	25	30.9			
	B	68	52	76.5	16	23.5			
	C	43	28	65.1	15	34.9			
	D	49	31	63.3	18	36.7			
	E	110	73	66.4	37	33.6	70	31.9	14

a. In terms of seawater control mean survival, which is assigned a value of 100%.

APPENDIX E

Clam Reburial Data Sheets

E1 Water Quality Measurements During Macoma balthica Reburial

E2 Number of Macoma balthica Reburied Over time

E3 Plots and ET50 calculations for clam reburial bioassays

APPENDIX E1

WATER QUALITY MEASUREMENTS DURING *MACOMA BALTHICA* REBURIAL

Sample	Replicate	Temp. (°C) 0 h	Temp. (°C) 24 h	Temp. (°C) 48 h	pH 0 h	pH 24 h	pH 48 h	D.O. (mg/L) 0 h	D.O. (mg/L) 24 h	D.O. (mg/L) 48 h	Salinity (ppt) 0 h	Salinity (ppt) 24 h	Salinity (ppt) 48 h
IS02	A	15.0	16.0	16.0	8.2	8.4	8.4	3.6	7.6	7.6	29	30	30
IS05	A	15.0	16.0	16.0	8.3	8.3	8.3	4.5	7.3	7.2	29	30	30
IS09	A	15.0	16.0	16.0	8.3	8.0	8.2	4.9	7.8	7.8	29	30	30
0A02	A	15.0	16.0	16.0	8.3	8.0	8.3	5.4	6.5	7.8	29	30	30
0A05	A	15.0	16.0	16.0	8.3	8.2	8.1	5.5	7.2	7.2	29	30	30
0A09	A	15.0	16.0	16.0	8.4	8.4	8.4	5.5	7.8	7.9	30	30	31
SP02	A	15.0	16.0	16.0	8.1	8.3	8.2	5.9	7.8	7.8	28	28	29
SP05	A	15.0	16.0	16.5	8.2	8.2	8.1	5.8	7.8	7.6	28	28	29
SP09	A	15.0	16.0	16.5	8.2	8.2	8.1	5.4	7.7	7.6	28	28	29
Control		15.5	16.0	16.5	8.5	8.5	8.1	4.7	7.8	7.8	28	28	27

APPENDIX E2

NUMBER OF MACOMA BALTHICA REBURIED OVER TIME (OUT OF 10)

Sample	Replicate	Time (min.) 1	2	5	10	20	30	40	50	60	75	90	105	120	140	160	180	220	250	320	960	1440	2400	2880
IS02	A	0	1	3	7	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
	B	0	0	3	6	6	8	8	8	8	8	8	8	8	8	8	8	8	8	8	9	9	9	9
	C	0	0	5	8	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
	D	0	0	2	5	7	10	10	10	10	10	10	10	10	10	9	10	10	10	10	10	9	10	10
	E	0	0	4	7	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
IS05	A	0	0	8	8	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
	B	0	0	4	7	7	7	7	8	9	9	10	10	10	10	9	9	9	9	9	10	10	10	10
	C	0	0	5	7	8	8	8	8	9	9	9	9	9	9	9	9	9	9	9	10	10	10	10
	D	0	0	2	5	8	8	8	8	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
	E	0	1	4	8	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
IS09	A	0	4	6	8	9	9	9	9	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
	B	0	1	5	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
	C	0	2	7	8	9	9	9	9	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
	D	0	3	8	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
	E	0	1	7	8	9	9	9	9	9	9	9	9	10	10	10	10	10	10	10	10	10	10	10
0A02	A	0	0	7	7	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
	B	0	4	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
	C	0	2	7	7	8	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
	D	2	3	6	7	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
	E	2	2	7	8	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	10	10	10	10
0A05	A	0	3	4	7	9	9	9	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
	B	0	3	5	7	7	7	8	9	9	9	9	9	9	9	9	9	9	9	9	10	10	10	10
	C	0	5	7	8	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
	D	1	3	5	8	9	9	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
	E	0	2	4	9	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
0A09	A	1	5	6	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
	B	0	2	5	8	8	8	9	9	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
	C	0	1	3	8	9	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
	D	0	1	3	6	6	8	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
	E	0	1	5	7	8	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9

Sample	Replicate		Time (min.) 1	2	5	10	20	30	40	50	60	75	90	105	120	140	160	180	220	250	320	960	1440	2400	2880
SP02	A			3	8	8	9	9	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
	B	no		6	8	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
	C	data		2	8	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
	D			4	5	7	7	8	8	8	8	8	8	8	8	8	8	8	8	8	8	10	10	10	10
	E			2	6	7	8	8	8	8	8	9	9	9	9	9	10	9	9	9	9	10	10	9	9
SP05	A		0	3	7	8	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
	B		0	2	6	9	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
	C		2	3	8	8	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
	D		0	1	4	7	8	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
	E		2	5	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
SP09	A			5	7	8	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
	B	no		4	8	9	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
	C	data		5	5	8	9	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
	D			1	3	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
	E			1	6	9	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Control	A		1	2	2	4	6	7	7	7	7	7	7	7	8	8	8	8	8	9	9	10	10	9	9
	B		4	4	5	9	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
	C		4	5	8	8	9	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
	D		1	4	6	9	9	9	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
	E		1	5	8	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9

APPENDIX F

Harpacticoid Copepod Bioassay Data Sheets

F1 Water Quality Measurements During Copepod Bioassays
F2 Survival of Adult Copepods During Bioassay Testing
F3 Numbers of Young Copepods Produced per Replicate
F4 Total Numbers of Young Copepods Produced Weekly in Each Sample and Relative Degree of Development
F5 Mean Numbers of Young Copepods Produced Per Week Per Adult $\pm$ Standard Deviation

APPENDIX F1

WATER QUALITY MEASUREMENTS DURING COPEPOD BIOASSAYS

Sample	pH DAY 1	2	3	4	5	6	7	8	* 9	10	11	12	13	14	15	16	17	* 18	19	20	21	22	23	24	* 25	26	27	28
Control		8.5	8.4	8.2	8.1	8.1	8.1	8.2	8.1	8.1	8.1	8.4	8.4	8.4	8.4	8.3	8.2	8.4	8.3	8.2	8.1	8.1	8.2	8.2	8.2	8.1	8.2	8.1
SP02		7.9	8.0	8.0	8.0	8.0	7.9	7.9	7.7	7.9	8.0	8.2	8.2	8.2	8.2	8.0	8.0	7.9	8.1	7.9	7.8	7.8	7.7	7.8	7.8	7.9	7.9	7.8
SP05		8.1	8.1	8.1	8.0	8.0	8.0	8.1	7.8	7.9	8.0	8.2	8.2	8.2	8.2	8.1	8.1	8.0	8.1	8.0	7.9	8.0	8.0	7.9	8.0	8.1	8.0	8.0
SP09		8.1	8.1	8.1	8.0	8.0	8.0	8.0	7.8	7.9	8.0	8.2	8.2	8.3	8.3	8.2	8.1	8.0	8.1	8.0	7.9	8.0	8.0	7.9	8.0	8.1	8.1	8.0
0A02		8.1	8.1	8.1	8.0	8.0	7.9	8.1	7.8	7.9	8.0	8.2	8.2	8.2	8.2	8.1	8.1	8.0	8.1	8.0	7.9	8.0	8.0	8.0	8.2	8.1	8.1	8.0
0A05		8.1	8.1	8.1	8.0	8.0	8.0	8.1	7.8	7.9	8.0	8.2	8.2	8.2	8.2	8.1	8.1	8.1	8.1	8.0	7.9	8.0	8.0	8.0	8.2	8.1	8.1	8.0
0A09		8.1	8.1	8.0	8.0	8.0	8.0	8.1	7.8	7.9	8.0	8.1	8.2	8.2	8.2	8.1	8.1	8.1	8.1	7.9	7.9	8.0	8.0	8.0	8.2	8.1	8.1	8.0
IS02		8.1	8.0	8.0	8.0	8.0	8.0	8.3	7.8	7.7	7.8	8.1	8.1	8.2	8.1	8.0	8.0	8.0	8.1	8.1	8.2	8.6	8.5	8.4	8.1	8.1	8.3	8.5
IS05		8.1	8.1	8.1	8.0	8.1	8.1	8.4	7.8	7.8	7.9	8.1	8.2	8.2	8.2	8.1	8.0	8.0	8.1	8.0	8.0	8.3	8.3	8.2	8.1	8.1	8.1	8.1
IS09		8.1	8.1	8.0	8.0	8.0	8.0	8.1	7.8	7.8	7.9	8.1	8.1	8.2	8.1	8.0	8.0	8.0	8.1	7.9	7.8	8.1	8.1	8.2	8.1	8.0	8.1	8.0

* all adult copepods were transferred to new sediment

WATER QUALITY MEASUREMENTS DURING COPEPOD BIOASSAYS

Sample	Dissolved Oxygen (mg/L) Day 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Control	7.8	7.4	7.8	7.8	7.7	7.4	7.3	7.3	7.3	7.4	7.3	7.1	7.2	6.8	7.3	7.3	7.1	7.3	7.2	7.2	6.9	7.3	7.2	7.1	7.2	7.6	7.2	7.3
SP02	4.3	6.0	6.9	6.9	6.8	6.8	6.5	6.4	5.9	6.4	6.4	6.2	6.4	6.1	6.5	6.4	6.3	5.9	6.2	6.2	6.0	6.1	6.0	6.1	6.0	6.4	6.4	6.0
SP05	4.8	6.1	6.9	6.9	6.9	6.8	6.5	6.4	5.5	6.2	6.5	6.1	6.2	6.0	6.5	6.4	6.2	6.0	6.2	6.3	6.2	6.4	6.3	6.2	6.2	6.5	6.4	6.3
SP09	4.8	6.1	6.9	6.9	6.9	6.9	6.3	6.2	5.4	6.1	6.5	6.2	6.0	5.9	6.2	6.1	6.0	6.0	6.2	6.3	6.2	6.4	6.4	6.2	6.2	6.5	6.5	6.3
0A02	5.1	6.0	6.6	6.7	6.6	6.6	6.1	6.0	5.5	5.9	6.3	6.1	6.0	6.0	6.3	6.1	6.1	5.9	6.0	6.1	6.0	6.2	6.2	6.0	6.0	6.4	6.5	6.0
0A05	5.4	6.0	6.6	6.7	6.8	6.8	6.3	6.0	5.8	6.1	6.4	6.2	6.1	6.0	6.4	6.4	6.3	5.9	6.0	6.0	6.0	6.2	6.2	6.0	6.1	6.4	6.6	6.1
0A09	5.2	6.0	6.4	6.7	6.6	6.7	6.3	6.2	6.0	6.0	6.4	6.0	6.1	6.0	6.3	6.4	6.3	5.9	5.8	5.9	6.0	6.2	6.1	6.0	6.1	6.4	6.2	6.1
IS02	3.9	5.5	6.1	6.3	6.1	6.2	5.6	5.2	4.1	5.2	5.7	5.6	5.5	5.2	5.6	5.7	5.6	4.8	5.2	5.2	4.9	4.8	4.5	4.5	5.1	5.5	5.4	4.8
IS05	4.0	5.4	6.0	6.1	6.0	6.0	5.4	5.0	4.1	5.3	5.8	5.7	5.6	5.2	5.7	5.5	5.4	5.0	5.4	5.6	5.2	5.2	5.2	5.2	5.3	5.7	4.8	5.0
IS09	4.3	5.6	6.2	6.3	6.2	6.4	5.8	5.7	4.1	5.5	6.1	5.8	5.7	5.8	6.0	5.9	6.0	5.3	5.7	5.8	5.7	5.8	5.7	5.6	5.5	6.1	5.8	5.4

WATER QUALITY MEASUREMENTS DURING COPEPOD BIOASSAYS

	Salinity (ppt) Day												
Sample	1	3	5	7	9	12	14	16*	18	20	22	25	28
Control	30	30	33	35	32	34	34	-	30	31	32	26	28
SP02	30	30	32	34	32	34	34	-	30	31	33	28	29
SP05	30	30	32	34	32	34	34	-	30	31	33	28	30
SP09	30	30	32	34	32	33	35	-	30	31	33	28	30
0A02	30	30	33	34	32	34	35	-	28	30	32	28	30
0A05	30	30	32	34	32	34	35	-	29	32	34	30	31
0A09	30	30	33	34	32	34	35	-	29	32	34	28	31
IS02	29	30	32	34	32	34	35	-	29	32	34	29	31
IS05	30	30	33	35	32	33	35	-	29	32	34	29	31
IS09	30	30	34	35	32	34	36	-	29	32	34	30	30

* meter not functioning properly

WATER QUALITY MEASUREMENTS DURING COPEPOD BIOASSAYS

Temperature (°C)

Sample	Day 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Control	17.8	19.0	18.0	18.0	17.0	17.0	17.5	17.0	17.0	17.5	18.0	19.0	20.0	19.0	18.5	19.5	19.5	19.0	19.0	19.5	20.0	20.0	19.5	19.0	19.0	19.0	19.0	19.5
SP02	18.2	19.5	18.5	18.5	18.0	18.0	18.0	18.0	18.0	18.0	18.5	19.0	20.0	20.0	19.0	20.0	20.0	19.5	19.5	20.0	20.5	20.0	20.0	19.0	19.0	19.0	19.0	20.0
SP05	18.0	19.5	18.5	18.5	18.0	18.0	18.0	17.5	18.0	18.0	18.5	19.0	20.0	20.0	19.0	20.0	20.0	19.5	19.5	20.0	20.5	20.0	20.0	19.0	19.0	19.0	19.0	20.0
SP09	18.0	19.5	18.5	18.5	17.5	18.0	18.0	17.5	18.0	18.0	18.5	19.0	20.0	20.0	19.0	20.0	20.0	19.5	19.5	20.0	20.5	20.0	20.0	19.0	19.0	19.0	19.0	20.0
0A02	17.8	19.2	18.5	18.0	17.0	17.5	17.5	17.0	17.5	17.5	18.0	19.0	20.0	20.0	18.5	19.5	19.5	19.0	19.0	19.5	20.0	20.0	19.5	19.0	19.0	19.0	19.0	19.5
0A05	17.8	19.0	18.0	18.0	17.0	17.0	17.5	17.0	17.5	17.5	18.0	19.5	20.0	20.0	18.5	19.5	19.5	19.0	19.0	19.5	20.0	20.0	19.5	19.0	19.0	19.0	19.0	19.5
0A09	17.5	19.0	18.0	18.0	17.0	17.0	17.5	17.0	17.5	17.5	18.0	19.0	20.0	20.0	18.5	19.5	19.5	19.0	19.0	19.5	20.0	20.0	19.5	19.0	19.0	19.0	19.0	19.5
IS02	17.5	19.0	18.0	18.0	17.0	17.0	17.5	17.0	17.5	17.5	18.0	19.0	19.5	19.5	18.5	19.5	19.5	19.0	19.0	19.0	20.0	20.0	19.5	19.0	19.0	19.0	19.0	19.5
IS05	17.5	19.0	18.0	18.0	17.0	17.0	17.5	17.0	17.5	17.5	18.0	19.0	19.5	19.0	18.5	19.5	19.5	19.0	19.0	19.0	20.0	20.0	19.5	19.0	19.0	19.0	19.0	19.5
IS09	17.5	19.0	18.0	18.0	17.0	17.0	17.5	17.0	17.5	17.5	18.0	19.0	19.5	19.0	18.5	19.5	19.5	19.0	19.0	19.0	20.0	20.0	19.5	19.0	19.0	19.0	19.0	19.5

APPENDIX F.2

SURVIVAL OF ADULT COPEPODS DURING BIOASSAY TESTING

Sample	Week 1	2	3	4
SP02	6[a]	6	5	5
SP05	8	8	8	8
SP09	8	7	7	7
OA02	8	8	8	7
OA05	8	8	8	8
OA09	8	8	8	8
IS02	7	7	7	7
IS05	8	8	6	6
IS09	7	7	7	7
Control	7	7	7	7

a. Numbers alive at the end of each week. Out of a total of 8 exposed to each sample at test initiation.

APPENDIX F.3

NUMBERS OF YOUNG COPEPODS PRODUCED PER REPLICATE[a]

Sample	Replicate	Week 1	2	3	4	Totals Weeks 1 - 4	$\bar{X} \pm$ S.D.
SP02	B	7	-[b]	0	4	11	
	C	17	112	0	1	130	
	D	65	93	0	0	158	
	E	1	125	1	9	136	
	F	0	114	-	-	114	
	G	35	55	1	0	91	
	H	11	90	0	-	101	
	I	0	119			119	
							107.5±44.2
SP05	B	41	133	5	0	179	
	C	16	60	6	1	83	
	D	19	133	0	0	152	
	E	27	61	0	1	89	
	F	23	114	0	0	137	
	G	13	69	0	0	82	
	H	5	98	0	0	103	
	I	13	127	5	0	145	
							121.2±36.8
SP09	B	1	60	0	0	61	
	C	4	2	0	0	6	
	D	6	35	4	0	45	
	E	0	111	-	-	111	
	F	2	48	7	0	57	
	G	0	82	0	1	83	
	H	0	18	27	0	45	
	I	0	32	62	1	95	
							62.9±33.1
OA02	B	24	107	46	0	177	
	C	6	5	27	0	38	
	D	0	73	55	0	128	
	E	14	9	1	0	24	
	F	15	47	48	0	110	
	G	8	61	49	0	118	
	H	4	78	59	1	142	
	I	4	72	83	-	159	
							112.0±54.6

Sample	Replicate	Week 1	2	3	4	Totals Weeks 1-4	$\bar{X} \pm$ S.D.
OA05	B	8	78	0	0	86	
	C	5	69	25	1	100	
	D	15	33	92	0	140	
	E	0	80	113	19	212	
	F	5	36	51	13	105	
	G	9	55	36	7	107	
	H	6	57	70	1	134	
	I	0	27	0	0	27	
							113.9±52.6
OA09	B	0	19	22	0	41	
	C	30	95	39	0	164	
	D	0	2	3	0	5	
	E	23	99	84	2	208	
	F	15	49	97	1	162	
	G	6	-	25	5	36	
	H	15	79	47	16	157	
	I	17	107	53	0	177	
							118.8±78.0
IS02	B	-	58	-	-	58	
	C	0	56	48	2	106	
	D	37	54	39	0	130	
	E	43	13	82	8	146	
	F	41	-	81	0	122	
	G	53	2	48	4	107	
	H	46	1	2	0	49	
	I	44	-	1	12	57	
							96.9±37.3
IS05	B	52	0	75	17	144	
	C	36	0	107	3	146	
	D	56	2	53	1	112	
	E	48	7	96	-	151	
	F	41	0	5	-	46	
	G	11	0	56	17	84	
	H	0	6	5	11	22	
	I	36	0	84	5	125	
							103.8±48.6
IS09	B		36	92	2	130	
	C		13	41	9	63	
	D		23	32	10	65	
	E		0	41	2	43	
	F		18	50	3	71	
	G		14	90	32	136	
	H		16	57	7	80	
	I	(Not counted - included in Week 2 counts)	-	-	-	-	
							84.0±35.3

Sample	Replicate	Week 1	2	3	4	Totals Weeks 1-4	$\bar{X} \pm$ S.D.
Control	B	74	20	107	34	235	
	C	61	27	86	10	184	
	D	15	-	-	-	15	
	E	114	56	141	54	365	
	F	22	4	4	0	30	
	G	10	39	7	0	56	
	H	49	104	106	32	291	
	I	110	88	58	16	272	
							181.0±132.6

a. One adult female exposed per replicate.
b. Dashes indicate loss of sample, usually due to death of adult.

APPENDIX F.4

TOTAL NUMBERS OF YOUNG COPEPODS PRODUCED WEEKLY IN EACH SAMPLE AND RELATIVE DEGREE OF DEVELOPMENT[a]

Sample	Week 1	2	3	4	Total (Weeks 1-4)[c]
SP02	136	708 (60)	2 (50)	14 (93)	860
SP05	157	795 (44)	16 (0)	2 (0)	970
SP09	13	388 (2)	100 (9)	2 (0)	503
OA02	75	452 (31)	368 (26)	1 (0)	896
OA05	48	435 (8)	387 (42)	41 (22)	911
OA09	106	450 (43)	370 (48)	24 (4)	950
IS02	264	184 (2)	301 (92)	26 (85)	775
IS05	280	15 (0)	481 (90)	54 (78)	830
IS09	-[b]	120	403 (61)	65 (12)	588
Control	455	338	509 (58)	146 (88)	1448

a. Selected treatments analysed in weeks 2-4 for degree of development. Values in brackets represent the percentage of the total number of young that are the copepodite form (i.e., developmentally more advanced).
b. Combined with week 2 count.
c. Sum of all copepods produced in each sample during weeks 1-4.

APPENDIX F.5

MEAN NUMBERS OF YOUNG COPEPODS PRODUCED PER WEEK PER ADULT ± STANDARD DEVIATION

Sample	Week 1	2	3	4
SP02	17 ± 23 (8)[a]	101 ± 24 (7)	0.33 ± 0.52 (6)	2.8 ± 3.8 (5)
SP05	20 ± 11 (8)	99 ± 32 (8)	2 ± 2.7 (8)	0.25 ± 0.46 (8)
SP09	1.6 ± 2.3 (8)	48 ± 35 (8)	14 ± 23 (7)	0.3 ± 0.5 (7)
OA02	9.4 ± 7.8 (8)	56 ± 35 (8)	46 ± 24 (8)	0.14 ± 0.38 (7)
OA05	6.0 ± 4.9 (8)	54 ± 21 (8)	48 ± 41 (8)	5.1 ± 7.3 (8)
OA09	13 ± 11 (8)	64 ± 42 (7)	46 ± 32 (8)	2.9 ± 5.6 (8)
IS02	38 ± 17 (7)	31 ± 28 (6)	43 ± 33 (7)	7.7 ± 4.7 (7)
IS05	35 ± 30 (8)	1.9 ± 2.9(8)	60 ± 39 (8)	9. ± 7. (6)
IS09	*	17 ± 11 (7)	58 ± 24 (7)	9.3 ± 10 (7)
Control	57 ± 41 (8)	48 ± 37 (7)	73 ± 52 (7)	21 ± 20 (7)

a. Numbers in parentheses are number of adults producing young.
* Not counted - combined with week 2 data.

APPENDIX G

Complete Species Data For Benthic Infauna

i) Taxon list with corresponding taxon codes - 67 taxa; codes 1 to 67 correspond to columns 1 to 67 in the raw data matrix.

ii) Complete data matrix: 45 rows (stations) by 67 columns (taxa); each row (or record) is distributed over 4 lines within this file.

Records 01-05 =	Station	OA02	(replicates 1-5)
Records 06-10 =	Station	OA05	(replicates 1-5)
Records 11-15 =	Station	OA09	(replicates 1-5)
Records 16-20 =	Station	SP02	(replicates 1-5)
Records 21-25 =	Station	SP05	(replicates 1-5)
Records 26-30 =	Station	SP09	(replicates 1-5)
Records 31-35 =	Station	IS02	(replicates 1-5)
Records 36-40 =	Station	IS05	(replicates 1-5)
Records 41-45 =	Station	IS09	(replicates 1-5)

iii) All values within matrix are numbers of individuals/0.1 m^2. Standardization to sq. meter requires multiplication by a factor of 10.

iv) Oligochaeta (not included in the data matrix), were collected as follows:

Station	Species	Numbers
SP05	Tubificoides wasselli	2
	T. brownae	1
SP09	T. wasselli	1
	T. brownae	1
IS05	T. brownae	1
IS09	T. brownae	1
OA05	Limnodrilus victoriensis	1

NOAA - San Francisco Bay Benthos Species List

Taxon code refers to the column number within the "raw" data matrix found on the following pages.

Taxon Code	Identification
1	Schistomeringos rudolphi
2	Harmothoe imbricata
3	Euchone analis
4	Anaitides longipes
5	Glycinde picta
6	Asychis sp.
7	Sigambra bassi
8	Chaetozone ? acuta
9	Sphaerosyllis pirifera
10	Amaena occidentalis
11	Leitoscoloplos pugettensis
12	Glycera capitata
13	Notomastus tenuis
14	Melinna oculata
15	Mediomastus californiensis
16	Polynoidae (frag)
17	Capitella capitata
18	Polydora brachycephala
19	Lumbrineris sp. (frag)
20	Nephtys sp.
21	Nephtys cornuta
22	Armandia brevis
23	Glycera americana
24	Nephtys ferruginea
25	Nereidae - heteronereid form
26	Gyptis brevipalpa
27	Scolelepsis squamata
28	Nephtys californiensis
29	Nephtys caecoides
30	Glycera sp.
31	Glycera convoluta
32	Barantolla americana
33	Heteromastus filiformis
34	Pholoe minuta
35	Cossura soyeri
36	Streblospio benedicti
37	Turbellaria - Platyhelminthes
38	Ampelisca abdita
39	Corophium sp.
40	Photis californica
41	Ampelisca ? hessleri
42	Caprella sp.
43	Cryptomya californica
44	Macoma expansa
45	Protothaca staminea
46	Solen sicarius
47	Musculus senhousia
48	Tapes philippinarum
49	Clinocardium fucanum
50	Macoma nasuta
51	Lyonsia californica
52	Transenella tantilla
53	Sarsiella zostericola
54	Leptochelia sp.
55	Eudorella pacifica
56	Ascideacea
57	Pachycerianthus fimbriatus
58	Nudibranchiata - Aoelidea
59	Golfingia hespera
60	Amphiuridae (juv)
61	Nemertea
62	Achelia nudiuscula
63	Pinnixa sp.
64	Schleroplax granulata
65	Cancer gracilis
66	Calliannassa gigas
67	Phoronis

Site	Station	Replicate
OA	02	1
		2
		3
		4
		5
OA	05	1
		2
		3
		4
		5
OA	09	1
		2
		3
		4
		5
SP	02	1
		2
		3
		4
		5
SP	05	1
		2
		3

0	32	0	0	0	6	0	0	4	0	0	0	0	0	0	0	0	0					
0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0					4
0	384	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0					
0	0	0	0	0	0	0	0	0	0	0	0	4										
0	16	0	0	7	4	0	0	0	0	0	0	0	0	0	0	0	0					
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0					5
0	606	3	0	1	0	0	1	0	0	1	0	0	0	0	0	0	0					
0	0	0	0	0	0	2	0	0	0	0	1	0										
0	17	1	0	12	4	0	1	3	0	0	0	0	0	0	0	0	0					
0	0	0	0	0	0	0	2	4	0	0	0	0	0	0	0	0	0	SP	09			1
0	870	20	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0					
2	0	0	0	0	0	1	0	0	0	0	1	0										
0	10	2	0	18	0	0	0	4	0	0	0	0	0	0	0	0	0					
0	0	0	0	0	0	0	2	4	0	0	0	0	0	0	0	0	0					2
0	870	20	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0					
2	0	0	0	0	0	1	0	0	0	0	1	0										
0	17	0	1	11	7	0	0	1	1	0	0	0	0	0	0	2	0					
0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0					3
0	355	10	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0					
0	0	0	0	0	0	0	0	0	0	0	0	1										
0	23	1	0	10	6	0	0	4	0	0	0	0	0	0	0	0	0					
0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0					4
11	050	7	0	3	1	0	1	0	1	0	0	0	0	0	0	2	0					
0	0	0	0	0	0	1	0	0	0	0	0	4										
0	6	2	0	10	3	0	1	1	0	0	0	0	0	0	0	0	0					
0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0					5
2	888	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0					
1	0	0	0	0	1	6	0	0	0	0	0	0										
0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15	0					
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	IS	02			1
0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0					
0	0	0	0	0	0	0	0	0	0	0	0	0										
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	54	0					
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0					2
0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0					
0	0	0	0	0	0	0	0	0	0	0	0	0										
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	56	0					
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0					3
0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0					
0	0	0	0	0	0	0	0	0	0	0	0	0										
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0					
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0					4
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0					
0	0	0	0	0	0	0	0	0	0	0	0	0										
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	102	0					
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0					5
0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0					
0	0	0	0	0	0	0	0	0	0	0	0	0										
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	24	0					
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	IS	05			1
0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0					
0	0	0	0	0	0	0	0	0	0	0	0	0										
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	24	0					
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0					2
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0					
0	0	0	0	0	0	0	0	0	0	0	0	0										
0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	113	0					
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0					3
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0					
0	0	0	0	0	0	0	0	0	0	0	0	0										
0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	54	0					
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0					4
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0					
0	0	0	0	0	0	0	0	0	0	0	0	0										
0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	75	0					
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0					5
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0					
0	0	0	0	0	0	0	0	0	0	0	0	0										
0	0	0	0	10	0	0	0	0	0	0	0	0	0	0	0	0	0					
0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	3	IS	09			1
0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	0	0	0					
0	0	0	0	0	1	0	0	2	0	0	0	0										
0	0	0	0	3	0	0	0	0	0	2	0	0	0	0	0	0	0					
0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	1					2
0	1	0	0	1	0	0	2	0	0	0	0	0	2	1	1	0	0					
0	0	0	0	0	0	0	0	0	0	0	0	0										
0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0					
0	0	0	0	0	0	0	1	0	0	1	0	0	0	1	0	0	1					3
0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0					
0	0	0	0	0	0	0	0	0	0	0	0	0	0									
0	0	0	0	6	0	2	0	0	0	2	0	0	0	0	0	0	0					
0	0	0	0	0	0	0	1	0	0	2	0	0	0	0	0	0	0					4
6	2	0	0	2	0	0	1	0	0	0	0	0	2	0	0	0	0					
0	0	0	0	0	0	0	0	0	0	0	0	0										
0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0					
0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	1					5
0	1	0	0	0	0	0	2	0	0	0	0	0	2	0	0	0	0					
0	0	0	0	0	0	0	0	0	0	0	0	0										